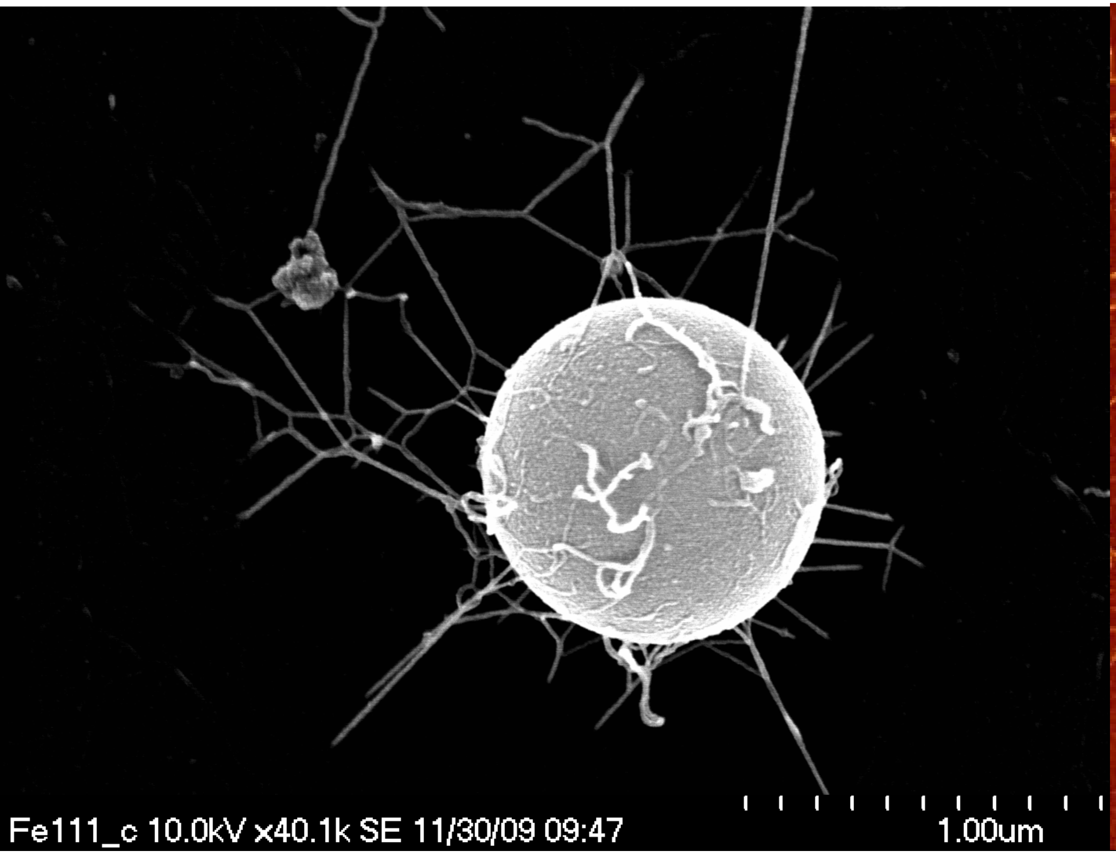
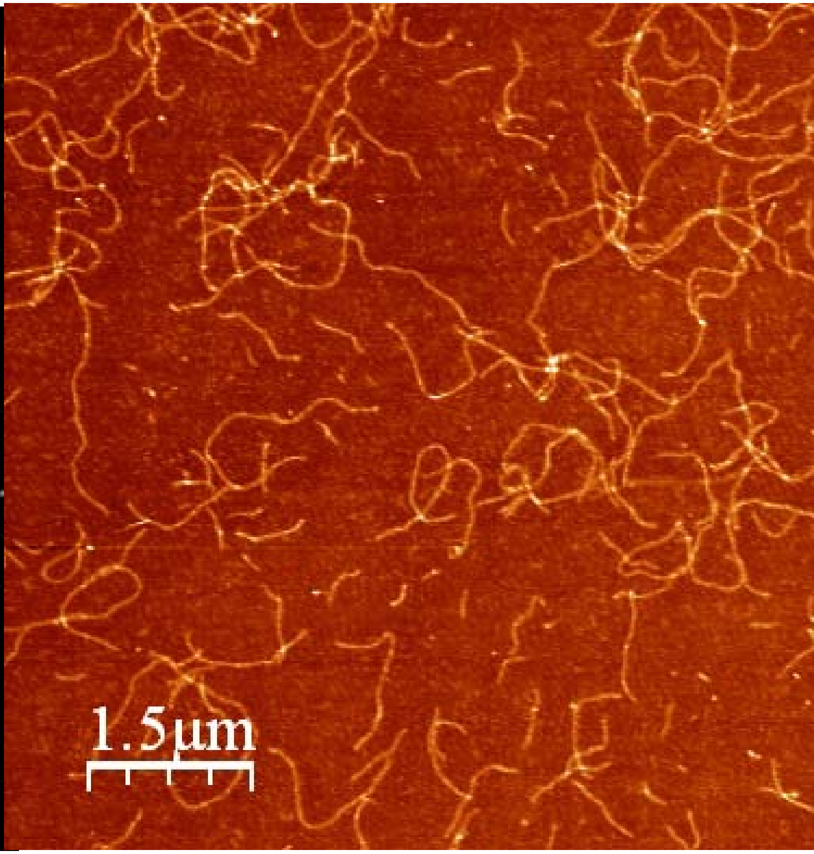


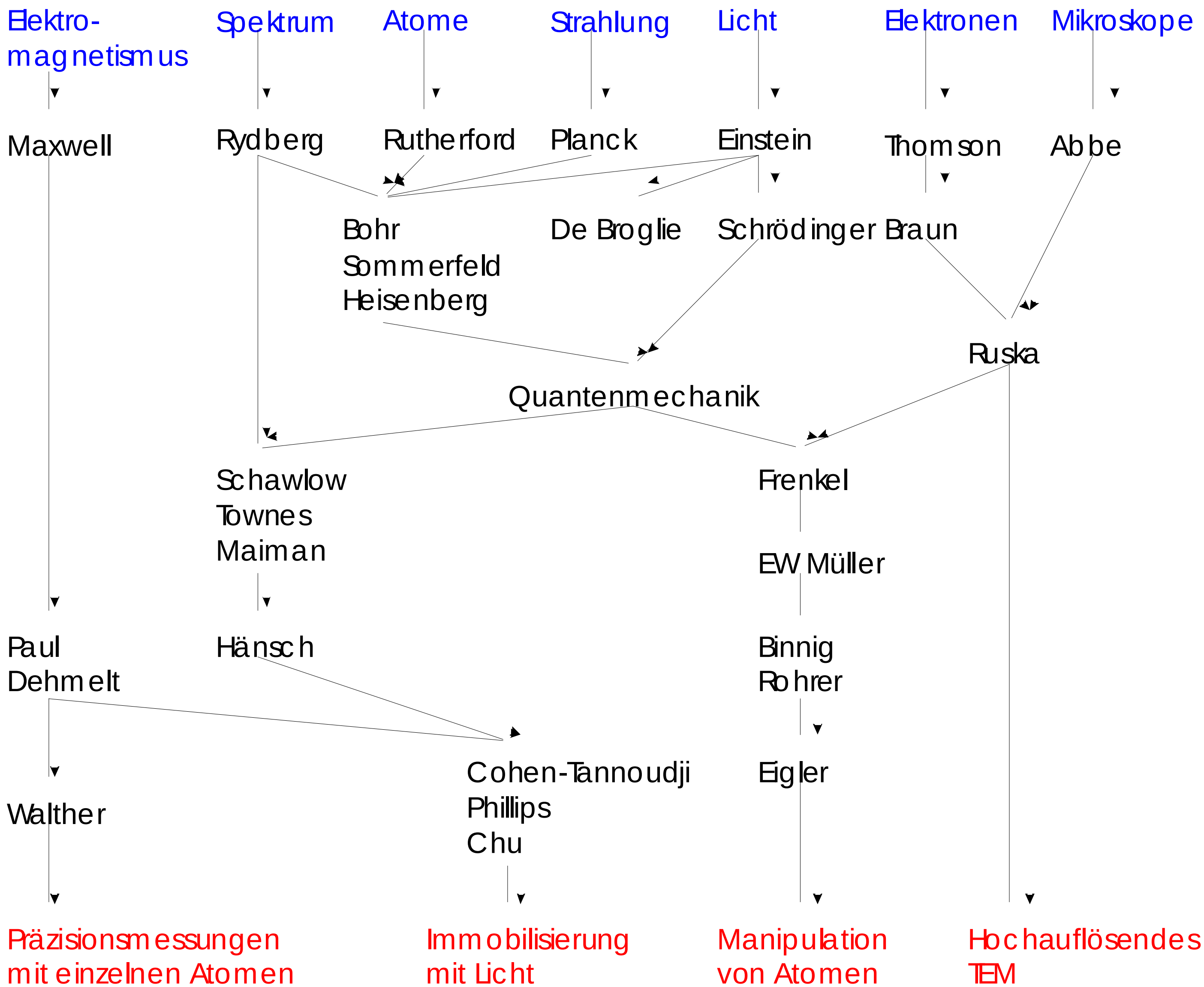


Rastersondenmikroskopie

Othmar Marti | 2010-07-29| Institute for Experimental Physics

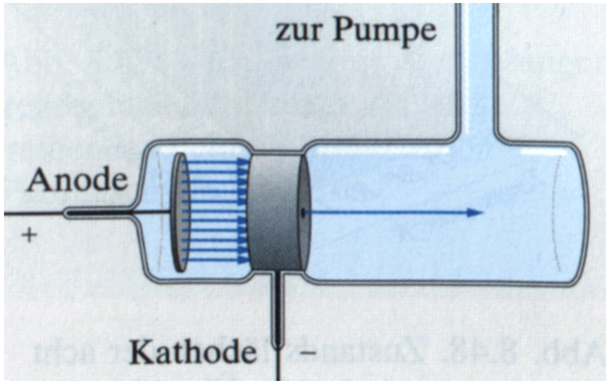
Übersicht

- Grundlagen
- Rastertunnelmikropskopie
- Rasterkraftmikroskopie
- Optische Falle


Elektro-magnetismus
Spektrum
Atome
Strahlung
Licht
Elektronen
Mikroskope
Maxwell
Rydberg
Rutherford
Planck
Einstein
Thomson
Abbe
Bohr
Sommerfeld
Heisenberg
De Broglie
Schrödinger
Braun
Ruska
Quantenmechanik
Schawlow
Townes
Maiman
Frenkel
EW Müller
Paul
Dehmelt
Hänsch
Binnig
Rohrer
Cohen-Tannoudji
Phillips
Chu
Eigler
Walther
Präzisionsmessungen mit einzelnen Atomen
Immobilisierung mit Licht
Manipulation von Atomen
Hochauflösendes TEM

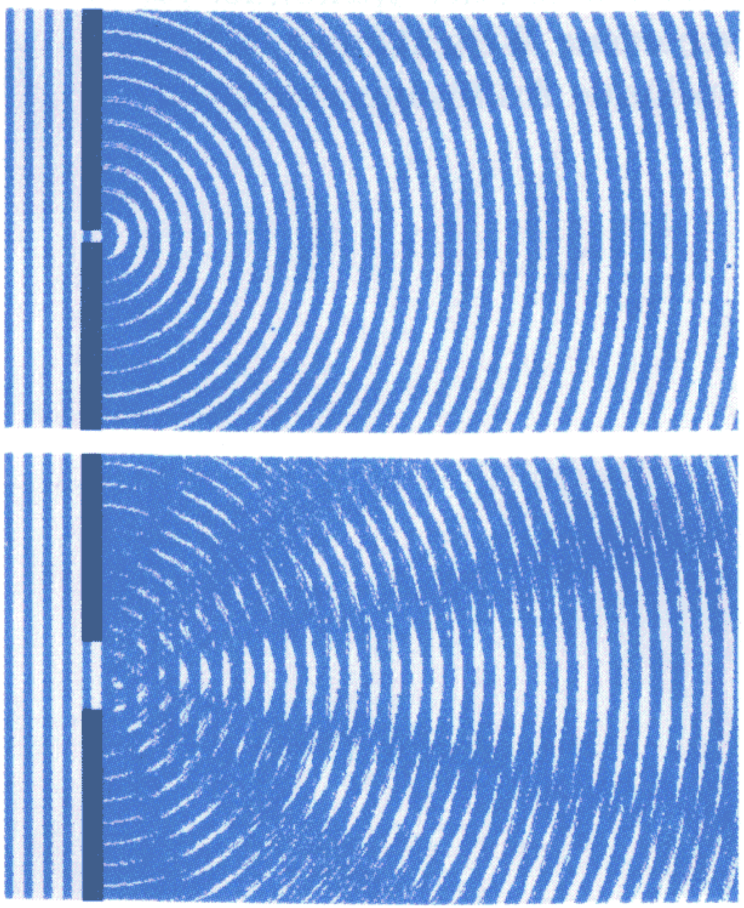
Röntgen und die Röntgenstrahlen

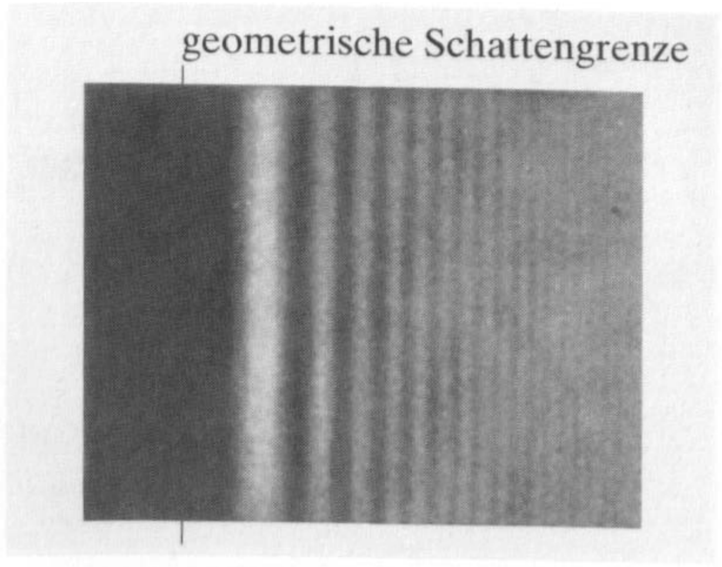
Wilhelm Conrad Röntgen (1845-1923)



Wellenlänge: 0,001 nm..1nm

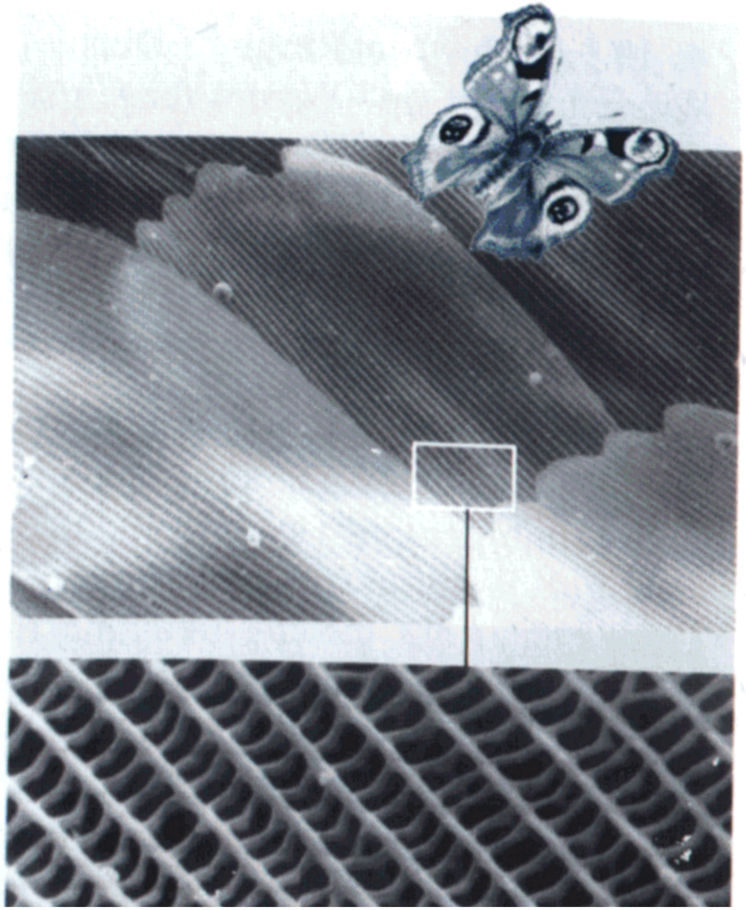
Phänomene mit Wellen

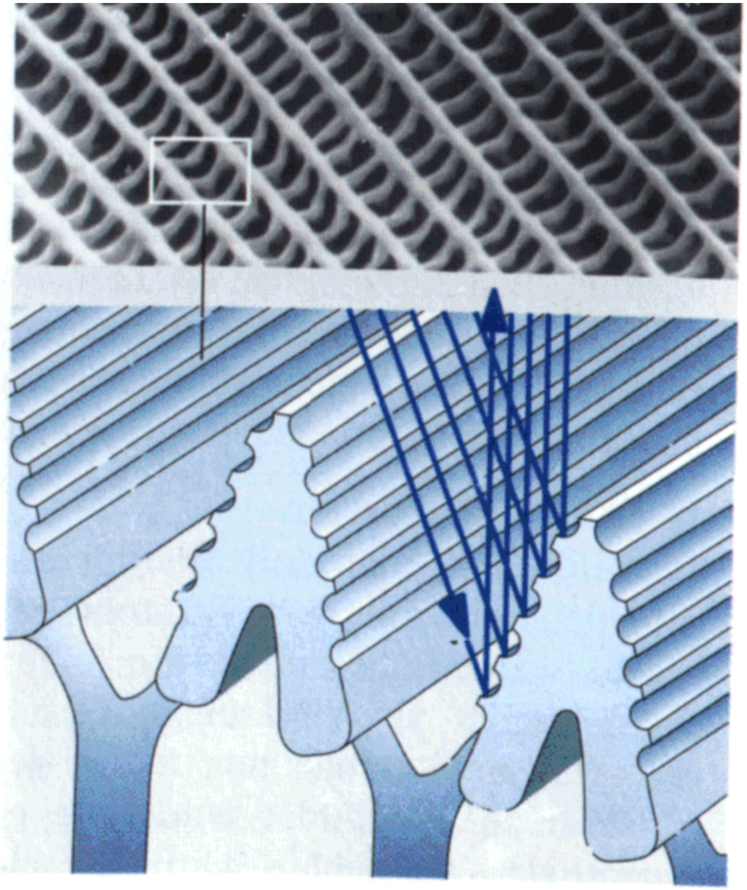




Wellen in der Theorie

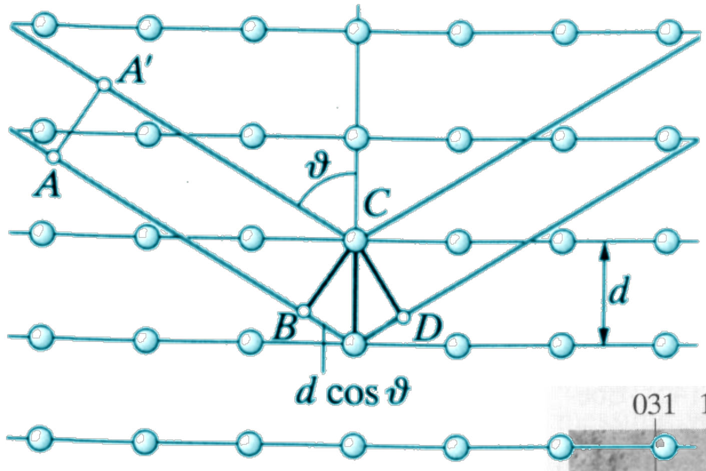
Schmetterling: Farben durch Interferenz



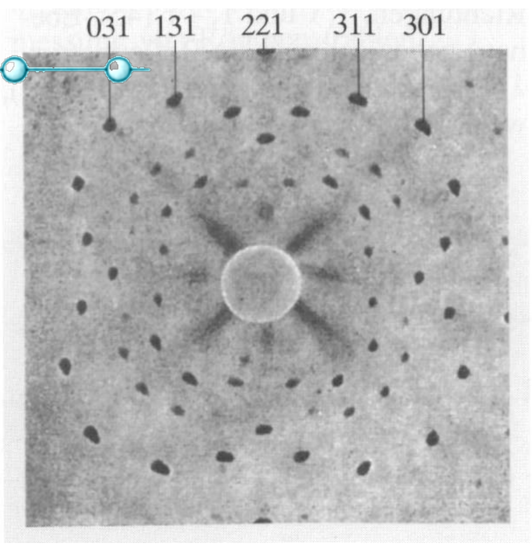


Laue: Beugung

Max von Laue



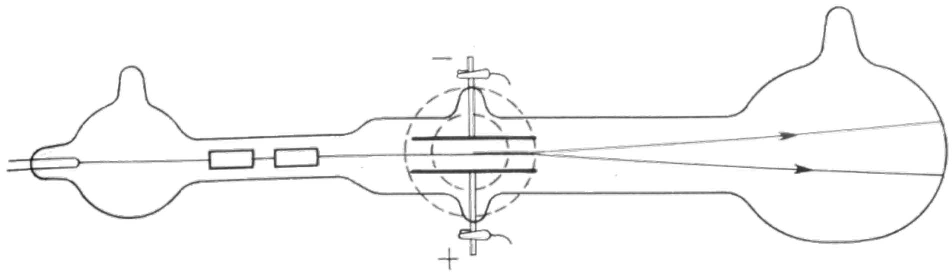
Interferenzeffekt
der
Röntgenstrahlen

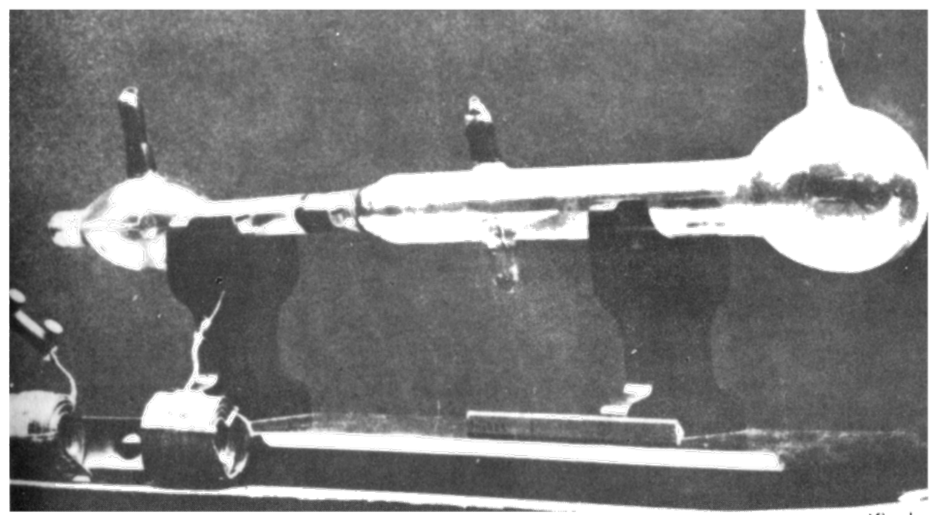


Becquerel und die Radioaktivität

Becquerel (1852-1908)
Entdeckte, dass Uransalze verpackte Filme schwärzen können.

J.J. Thomson und das Elektron

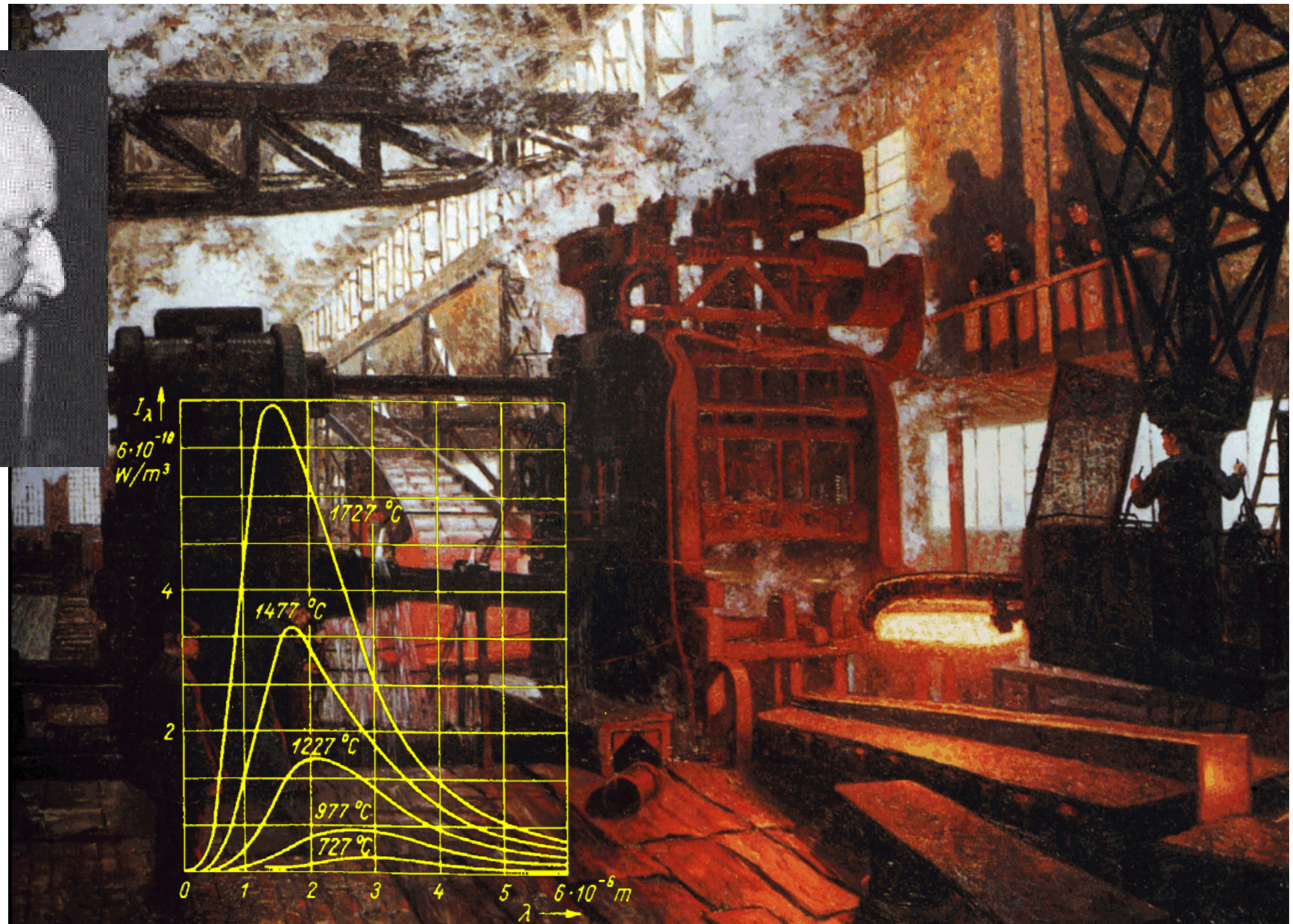




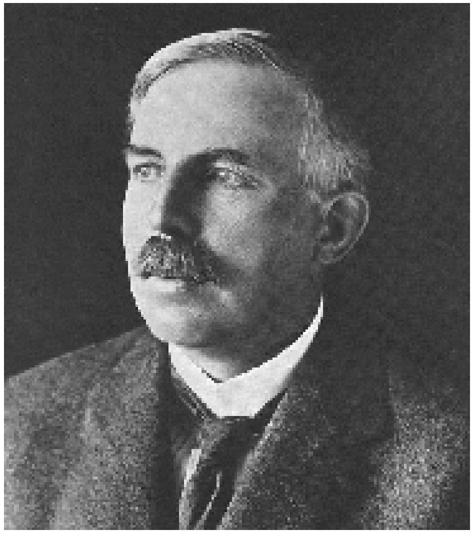
J.J. Thomson (1856-1940)
- Elektron
- Relativistische Massenzunahme

Planck: Strahlungsgesetz

Max Planck
(1858-1947)

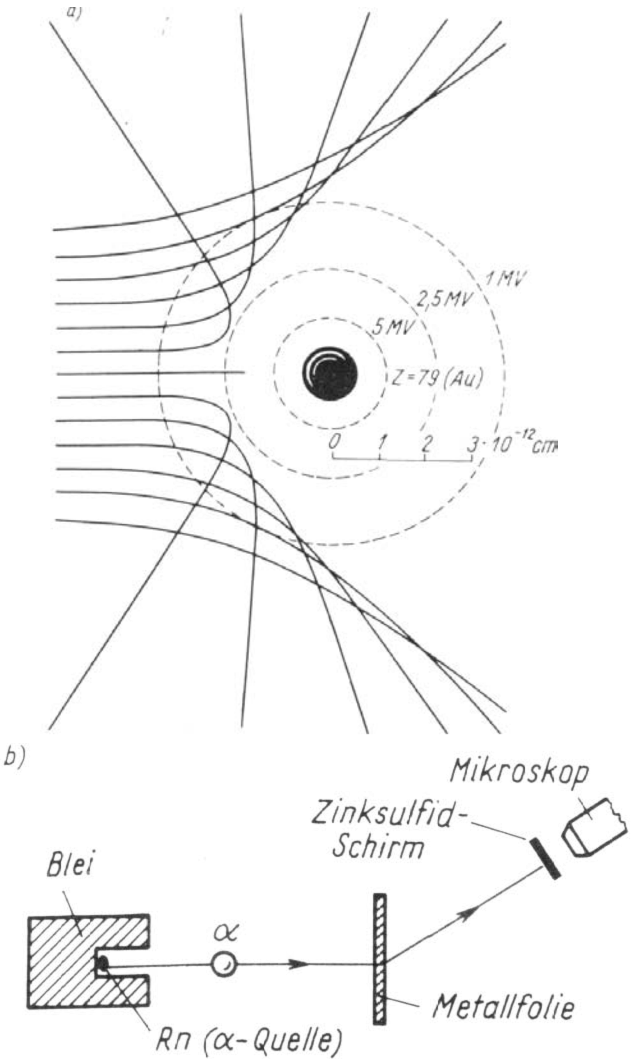


Rutherford und die α-Teilchen



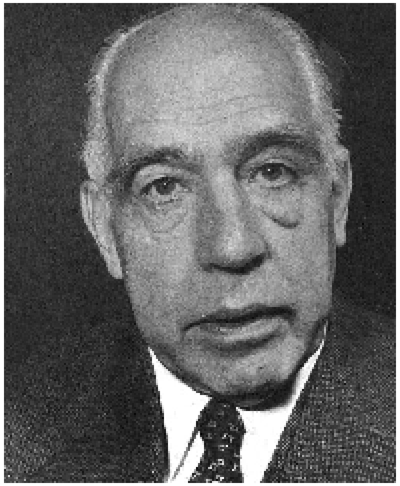
Ernest Rutherford (1871-1937)

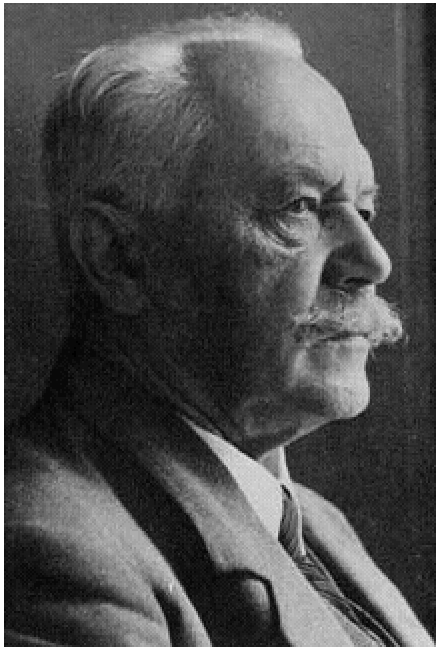
- Atommodell
- α- und β-Strahlen
- Neutronenvermutung



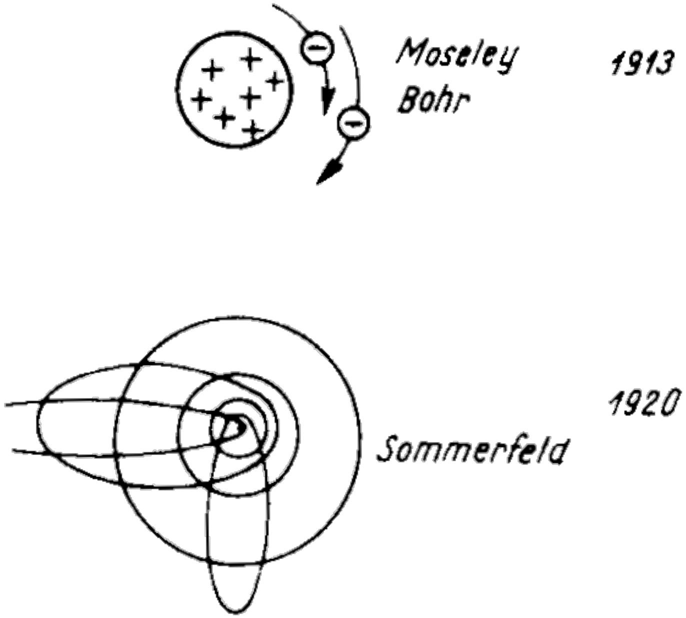
Bohr, Sommerfeld: Atommodelle

Niels Bohr
(1885-1962)



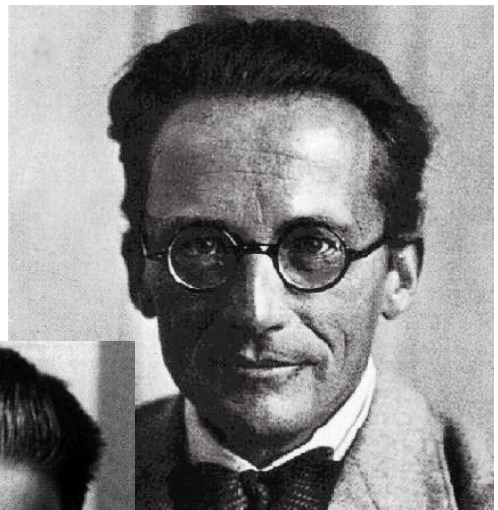


Arnold Sommerfeld
(1868-1951)



Schrödinger und Heisen-berg: Quantenphysik

Erwin Schrödinger (1887-1961)

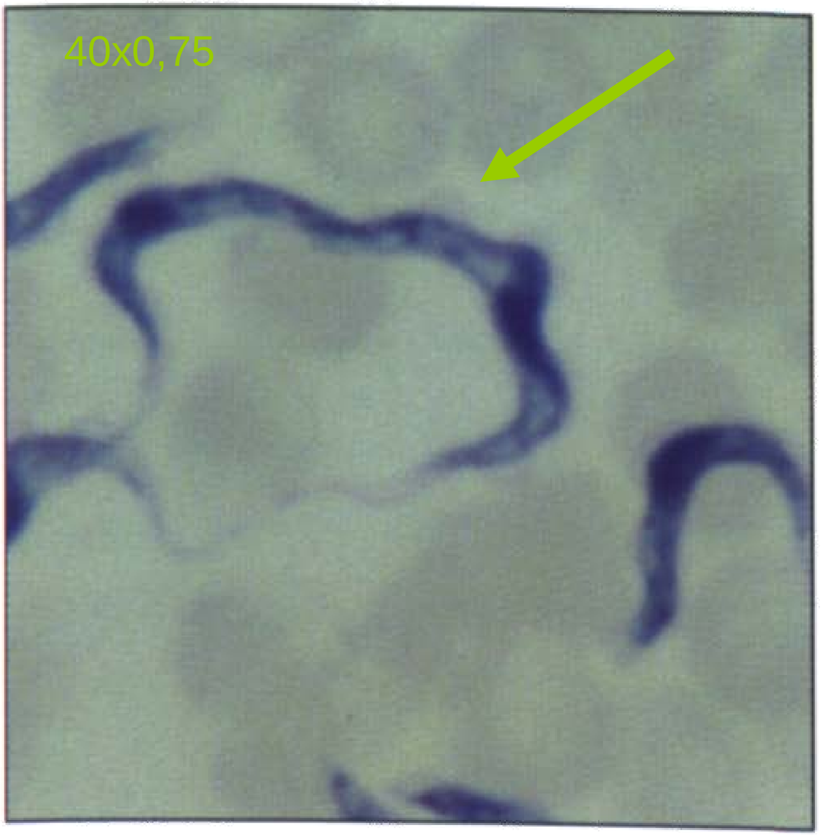


Werner Heisenberg (1901-1976)

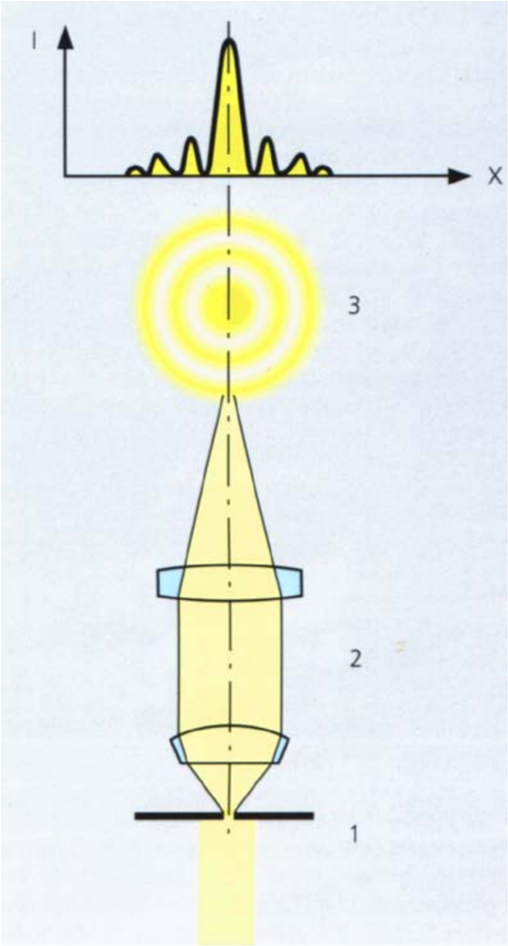
1925: Heisenberg: Matrizenmechanik
1926: Schrödinger: Wellenmechanik

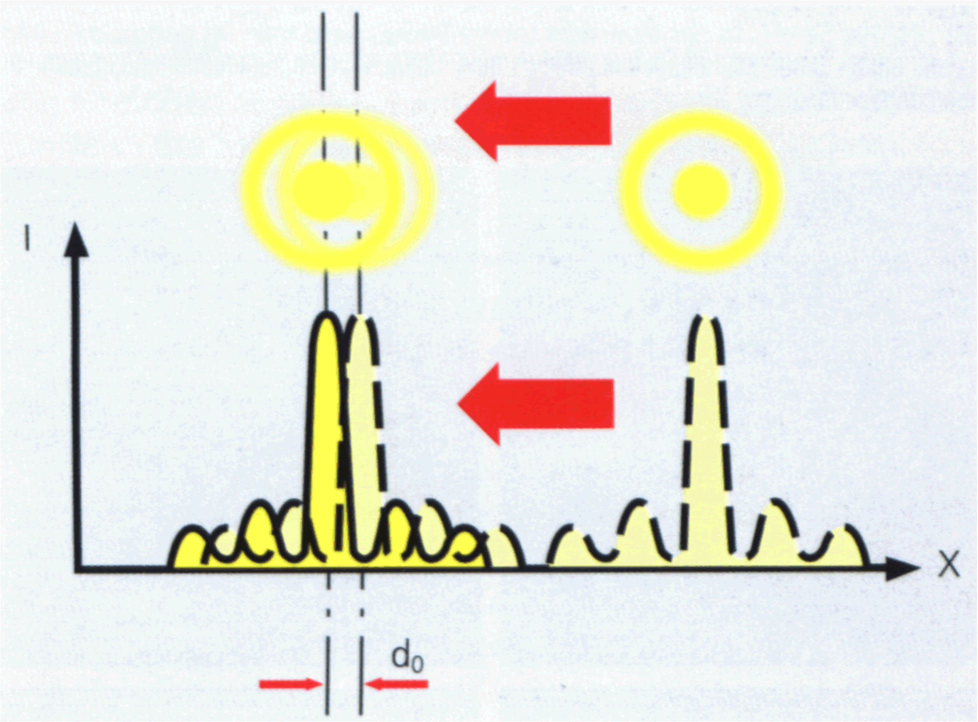
- Beide Formulierungensind äquivalent.

Optische Auflösung

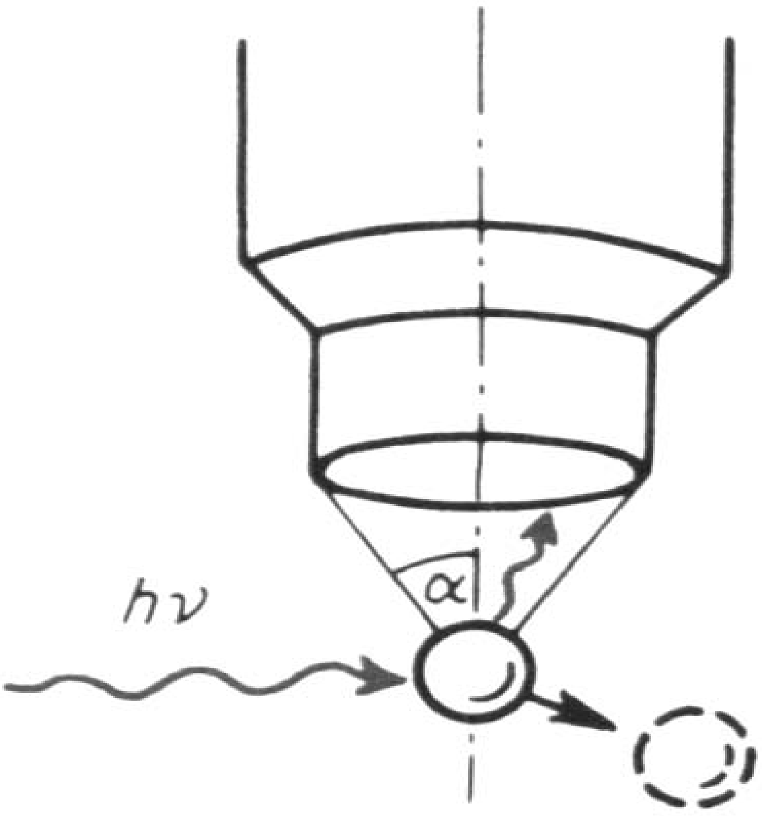


Optische Auflösung: Wellennatur des Lichtes



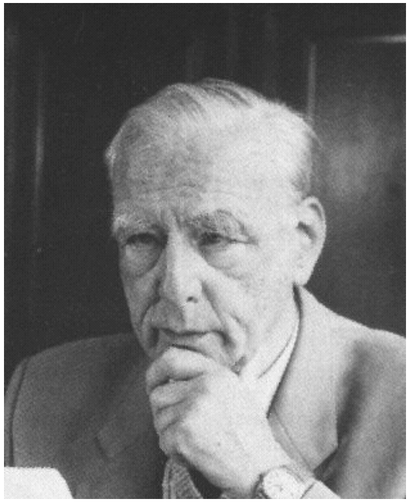


Können Mikroskope Atome abbilden?

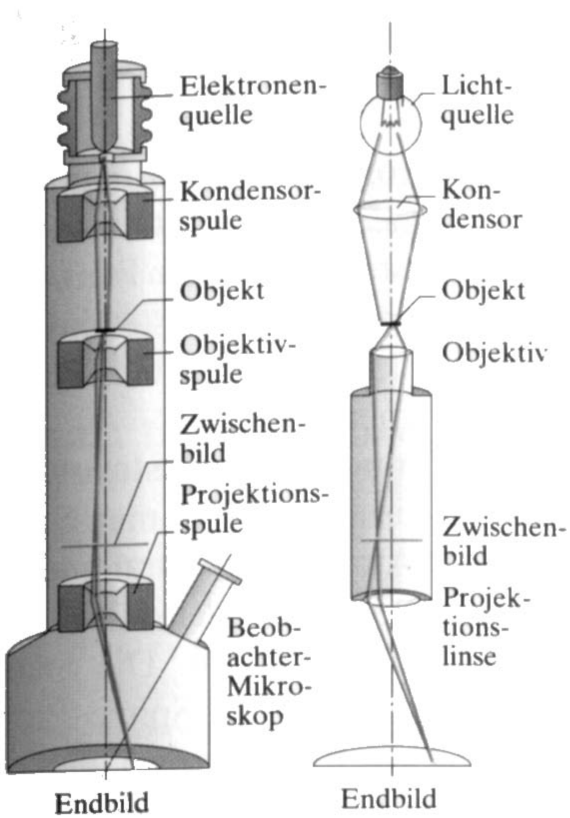


- Auflösung ist 1/2 Wellenlänge
- Jede Messung wirkt auf die Probe
- Mit optischen Mikroskopen sind Atome direkt nicht abbildbar

Ruska: Elektronenmikroskopie

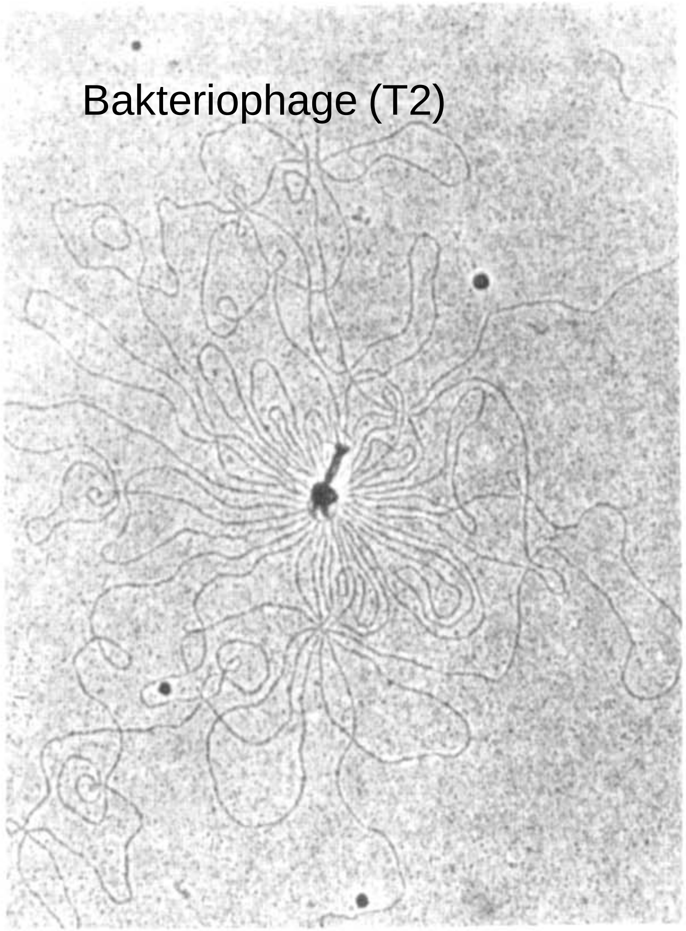


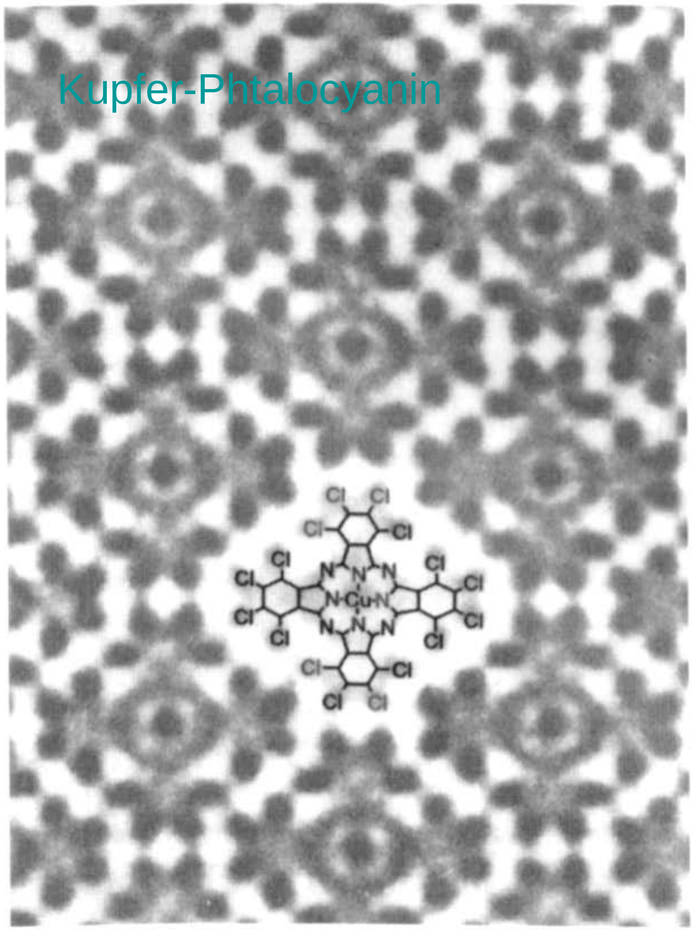
Ernst Ruska (1906-1988)



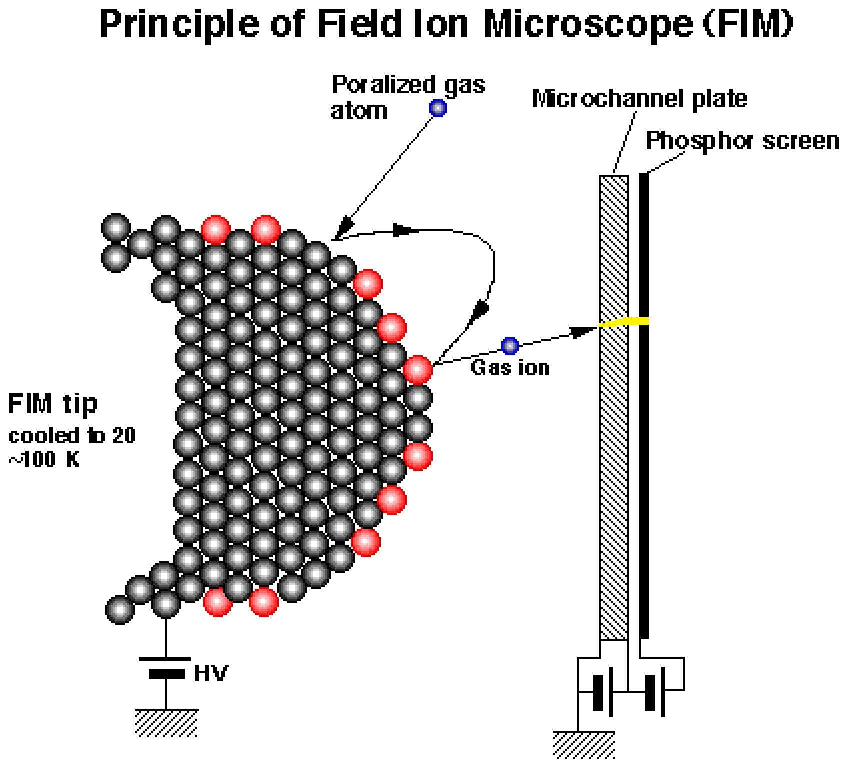
- Elektronen. Kleine Wellenlänge gibt höhere Auflösung

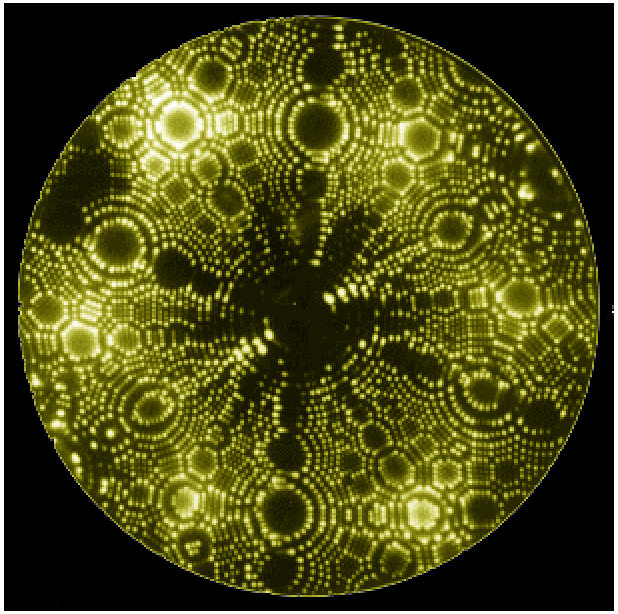
TEM-Bilder



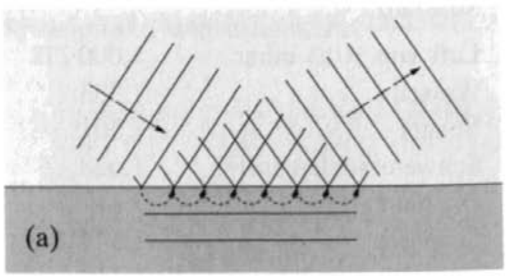


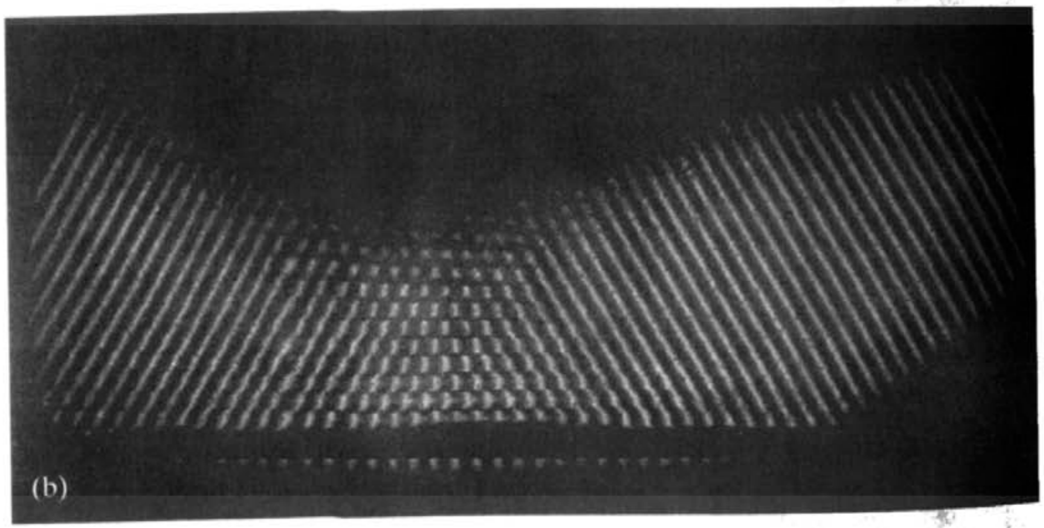
E.W. Müller: Feldionenmikroskopie





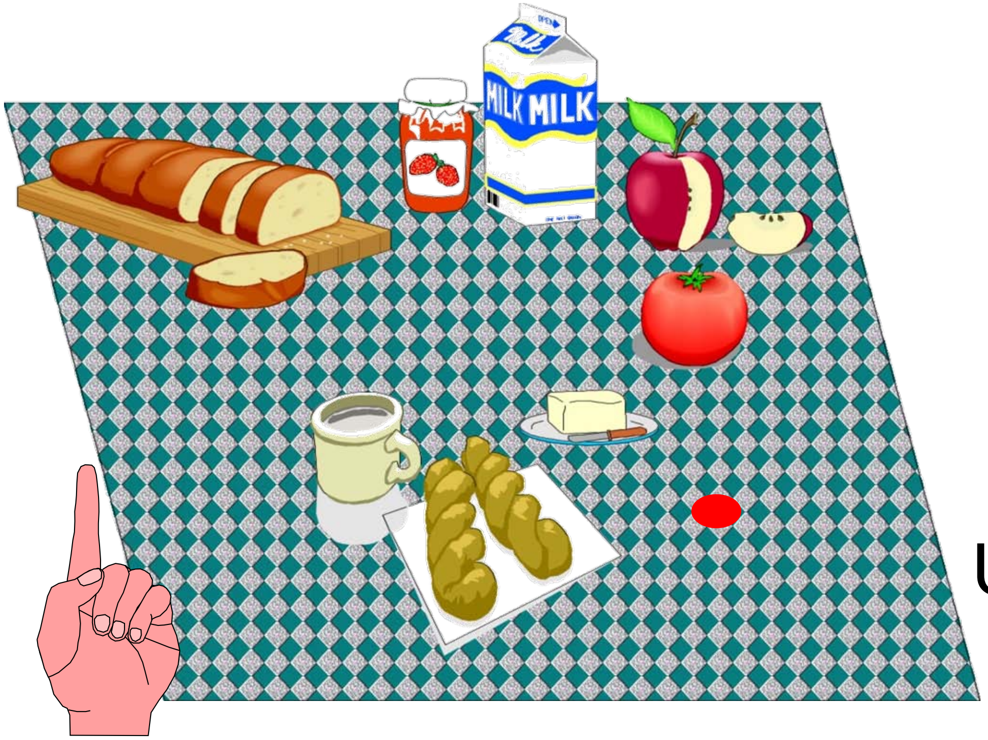
Frustrierte Totalrefelxion oder „Tunneln“





STM: Geschichte und etwas Physik

Wie misst ein Rasterkraftmikroskop?

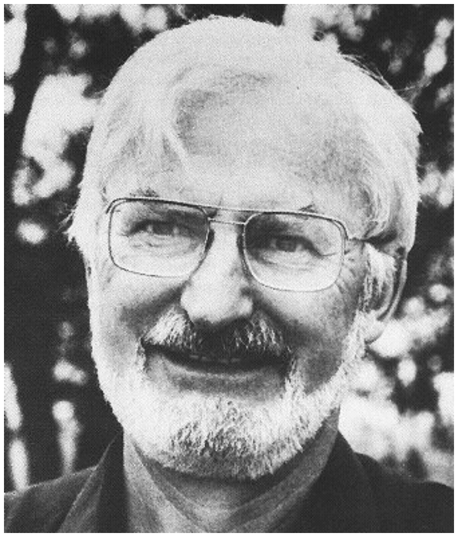


Im Dunkeln tastet man den Tisch mit der Hand ab

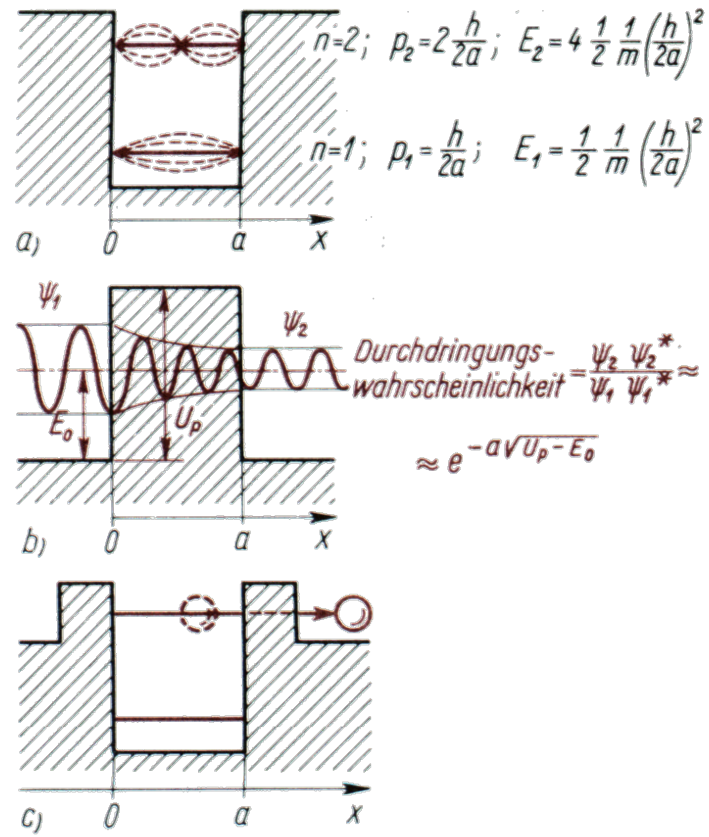
- hoch und runter
- hart und weich
- klebrig
- warm und kalt

Unser Gehirn setzt das Bild zusammen

Binnig and Rohrer: Scanning Tunneling Microscopy

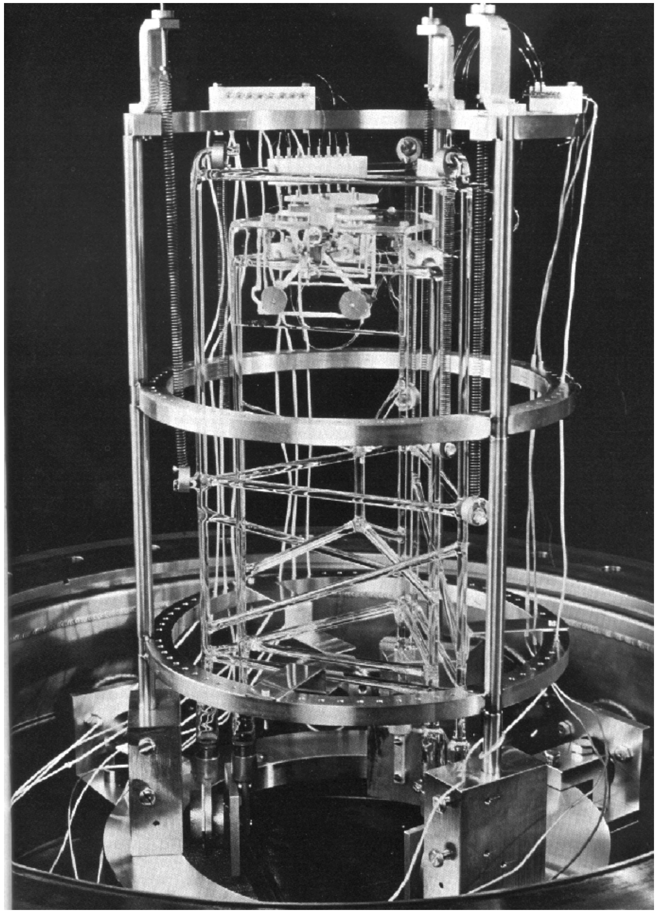


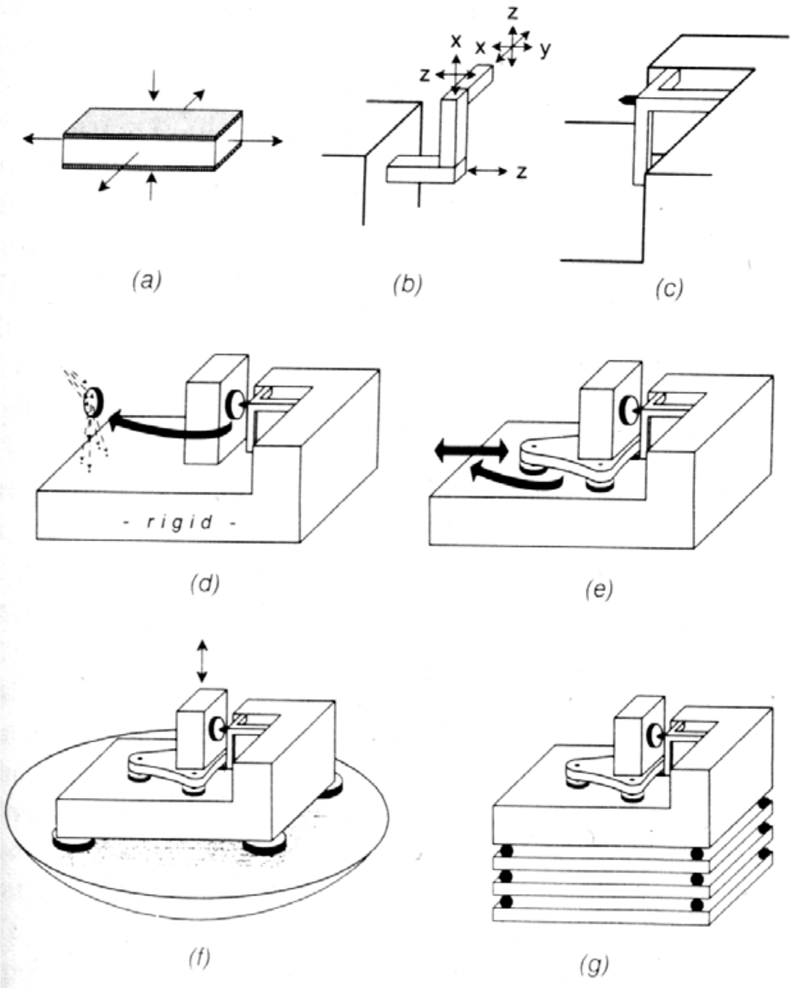
Heinrich Rohrer
(1933-)



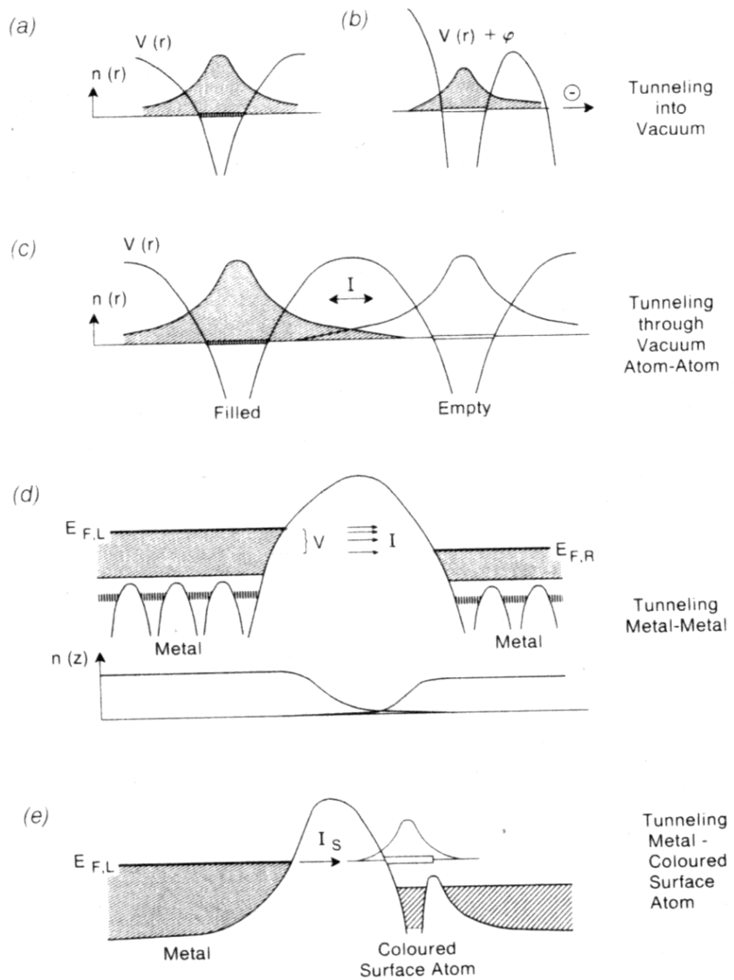
Gerd Binnig
(1947-)

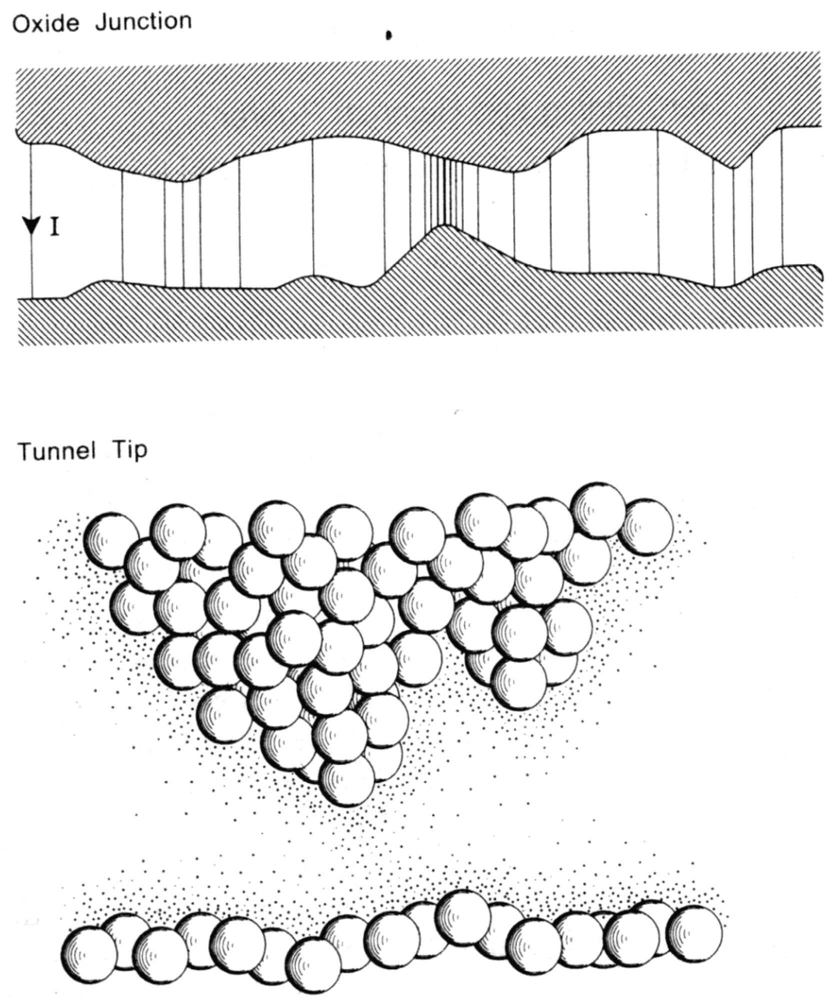
The Scanning Tunneling Microscope



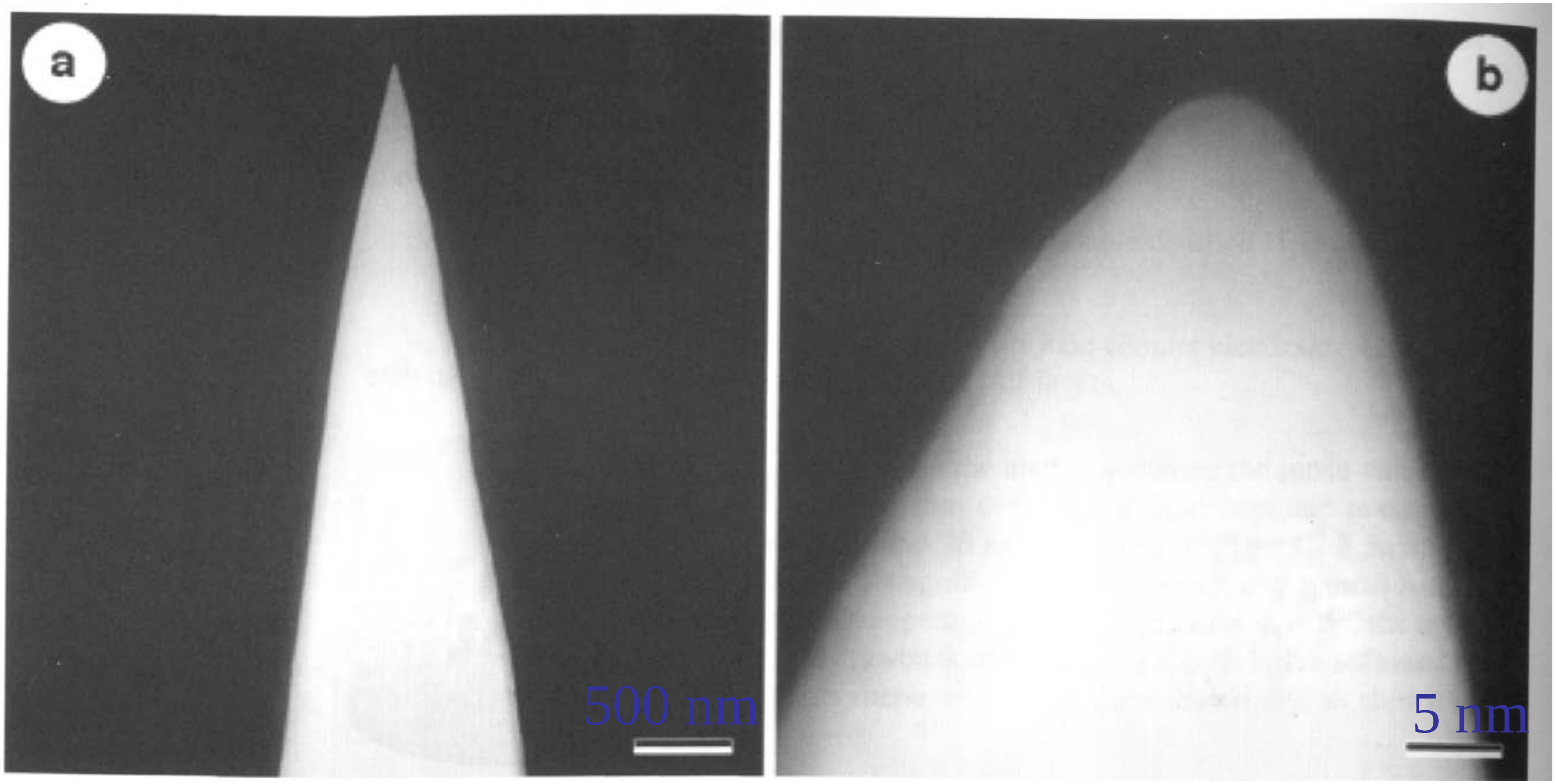


The Tunnel Effect

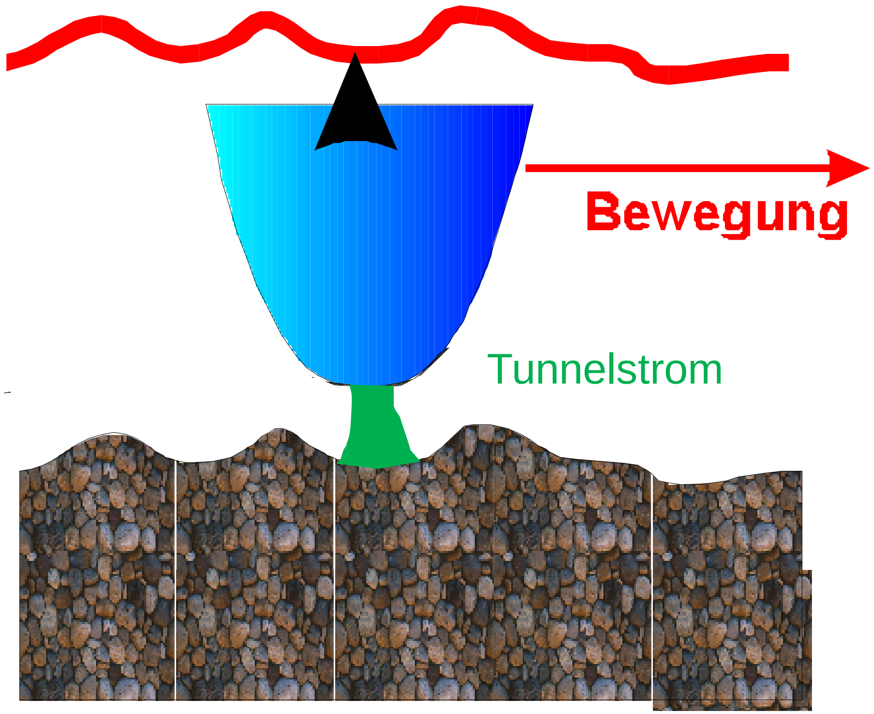




Some STM Tips made of Gold

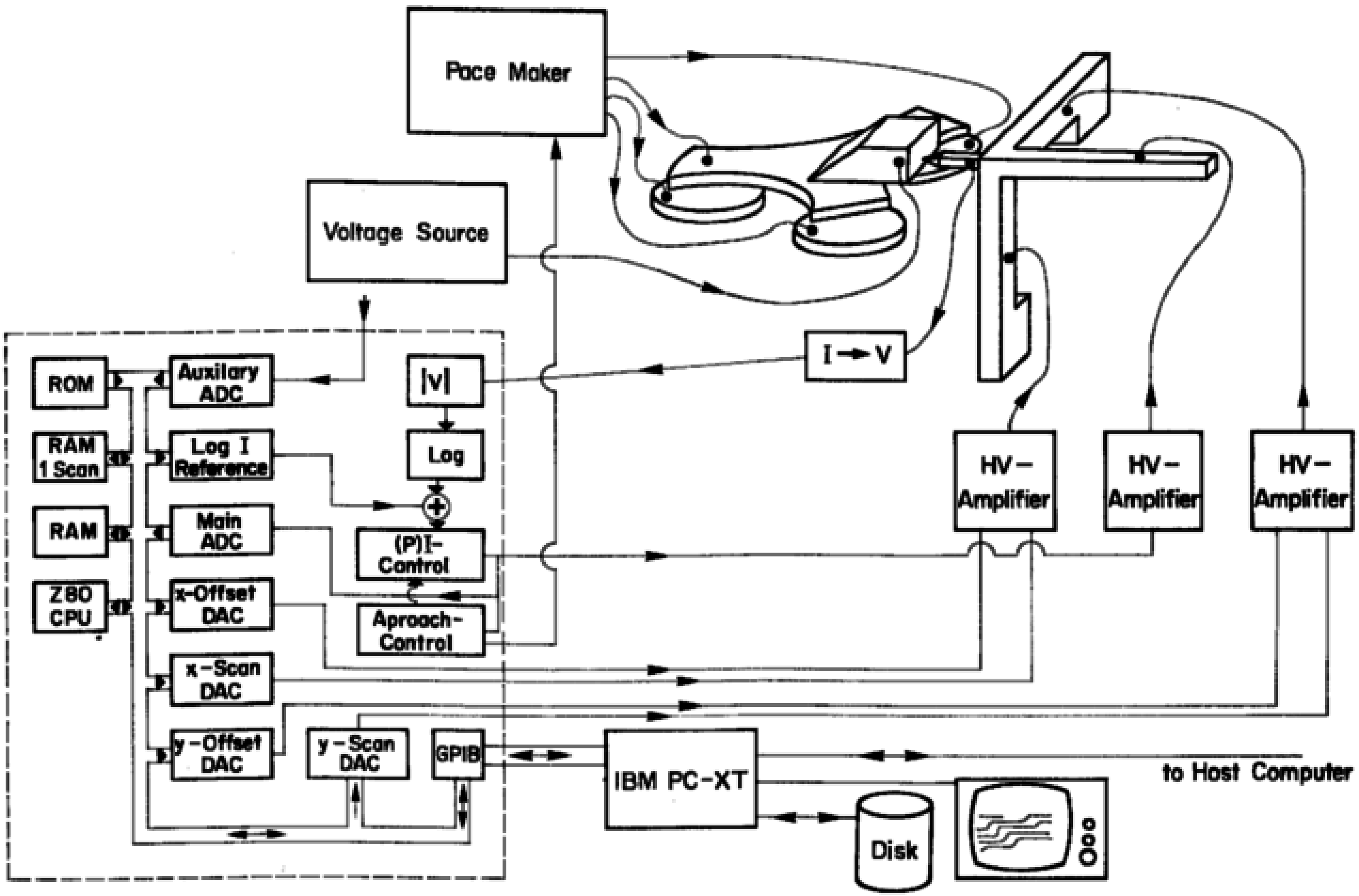


Messung von Profilen

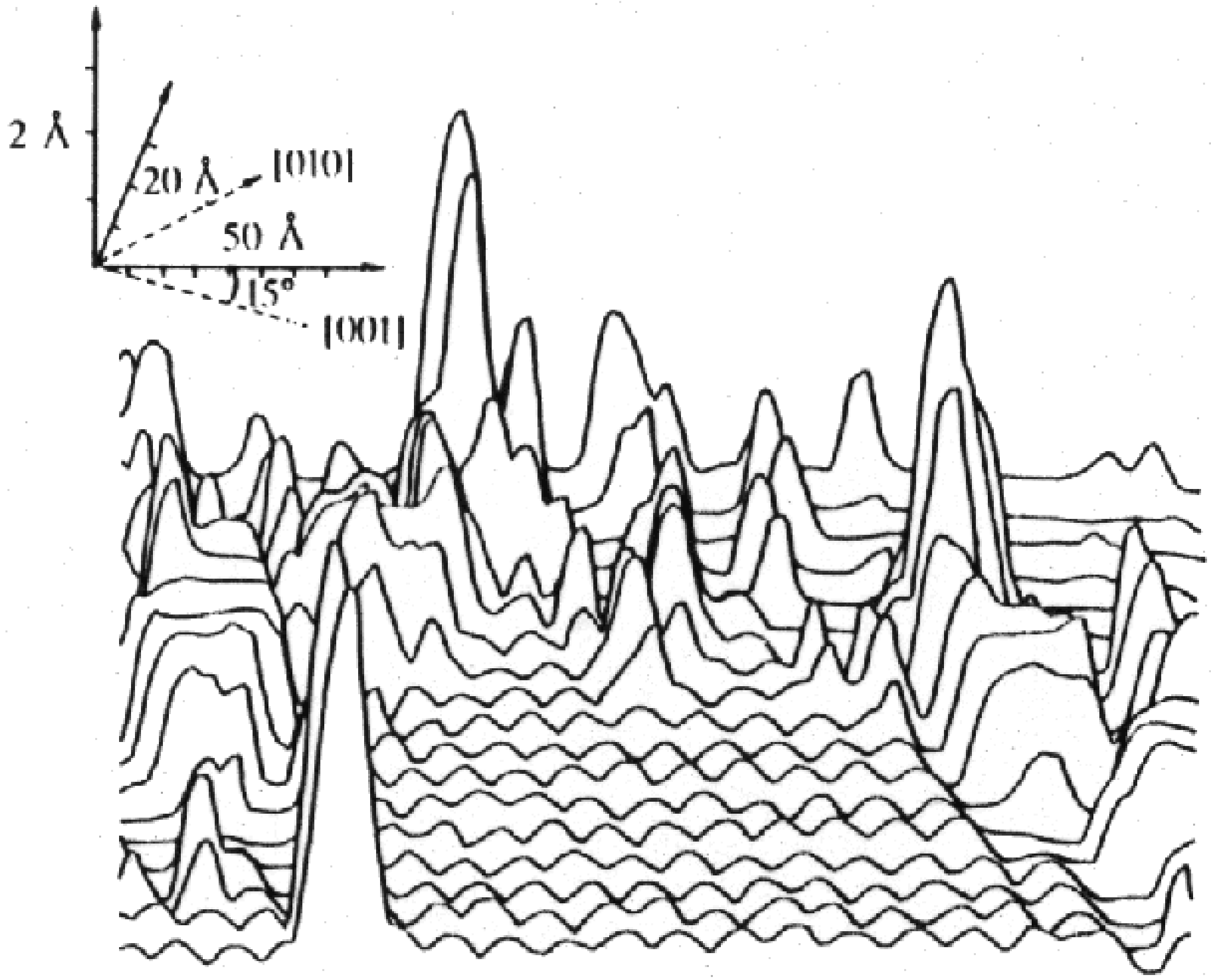


- Tunnelstrom wird konstant gehalten
- Höhen werden gemessen und mit der jeweiligen Position gespeichert

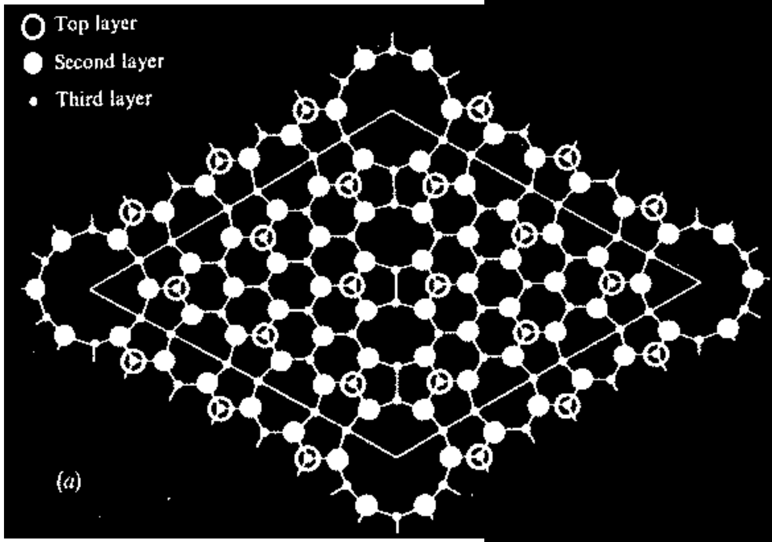
STM Steuerelektronik

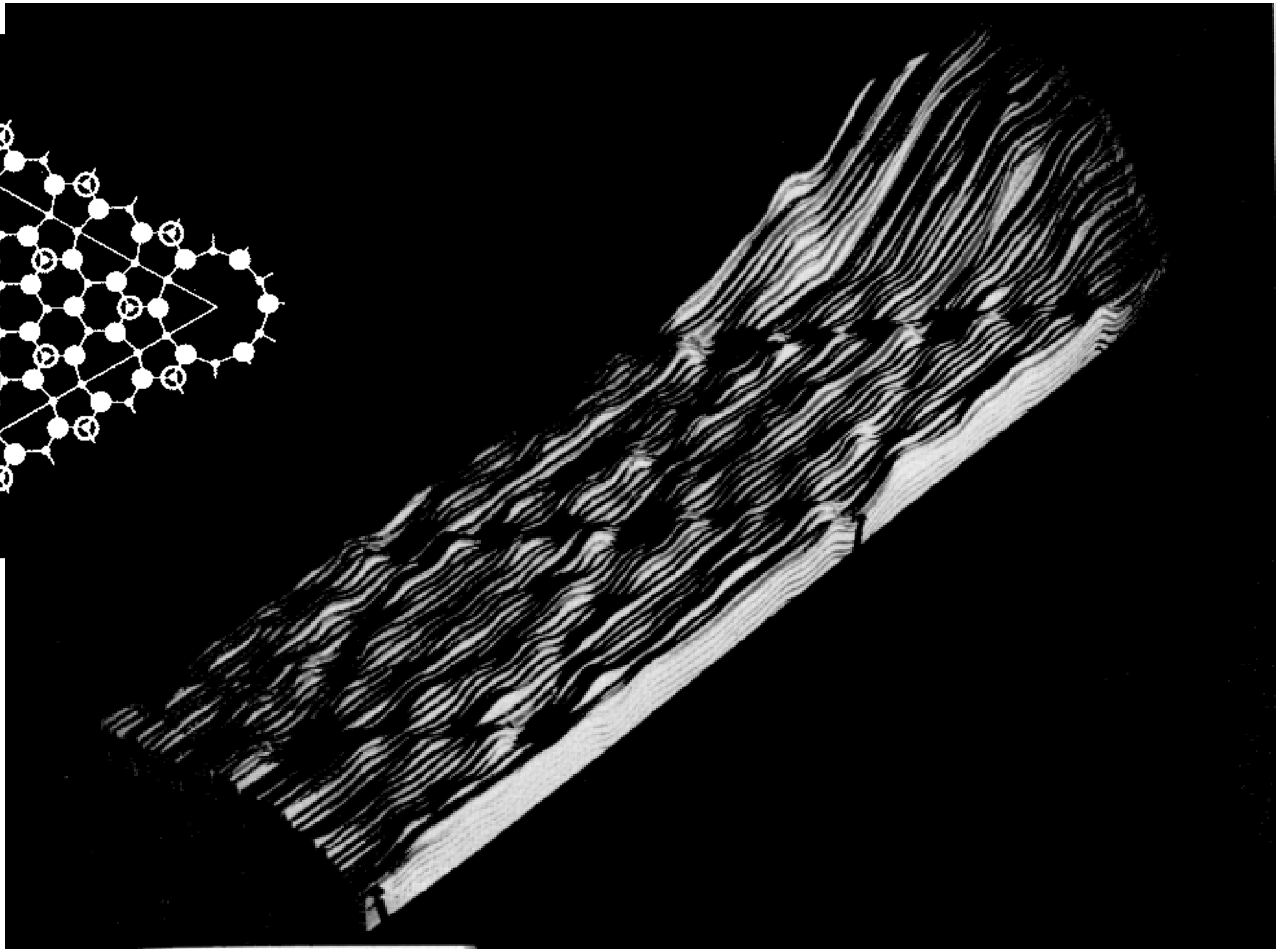


Behm: Platin(100)-Oberfläche mit C-Kontamination



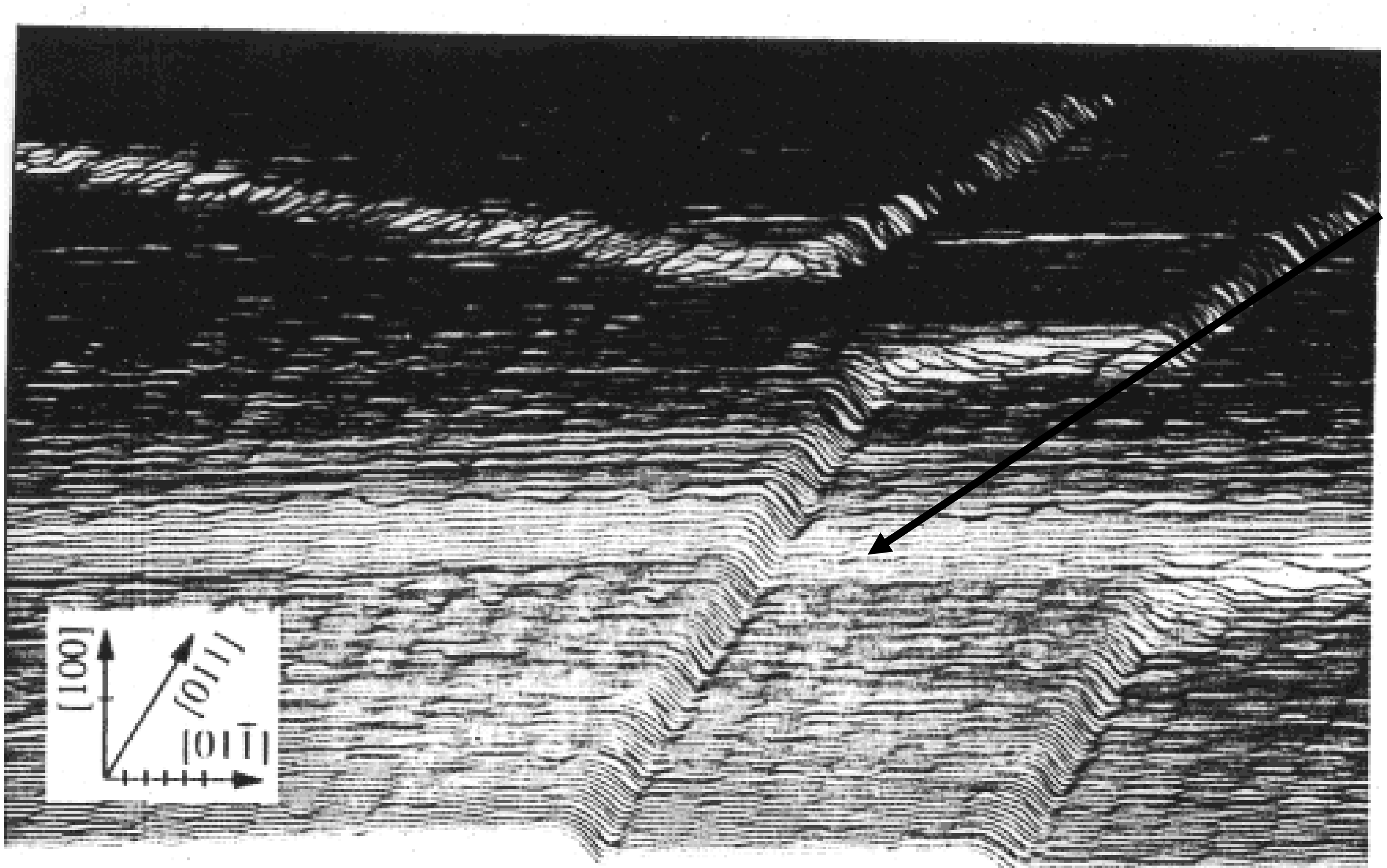
Binnig und Rohrer: Si(111) 7x7





Binnig G, **Rohrer** H, Gerber C, Weibel E. 7*7 reconstruction on Si(111) resolved in real space. *Physical Review Letters, 50/2, 10 Jan. 1983, pp.120-3.*

Binnig und Rohrer:
Au(100) 5x1

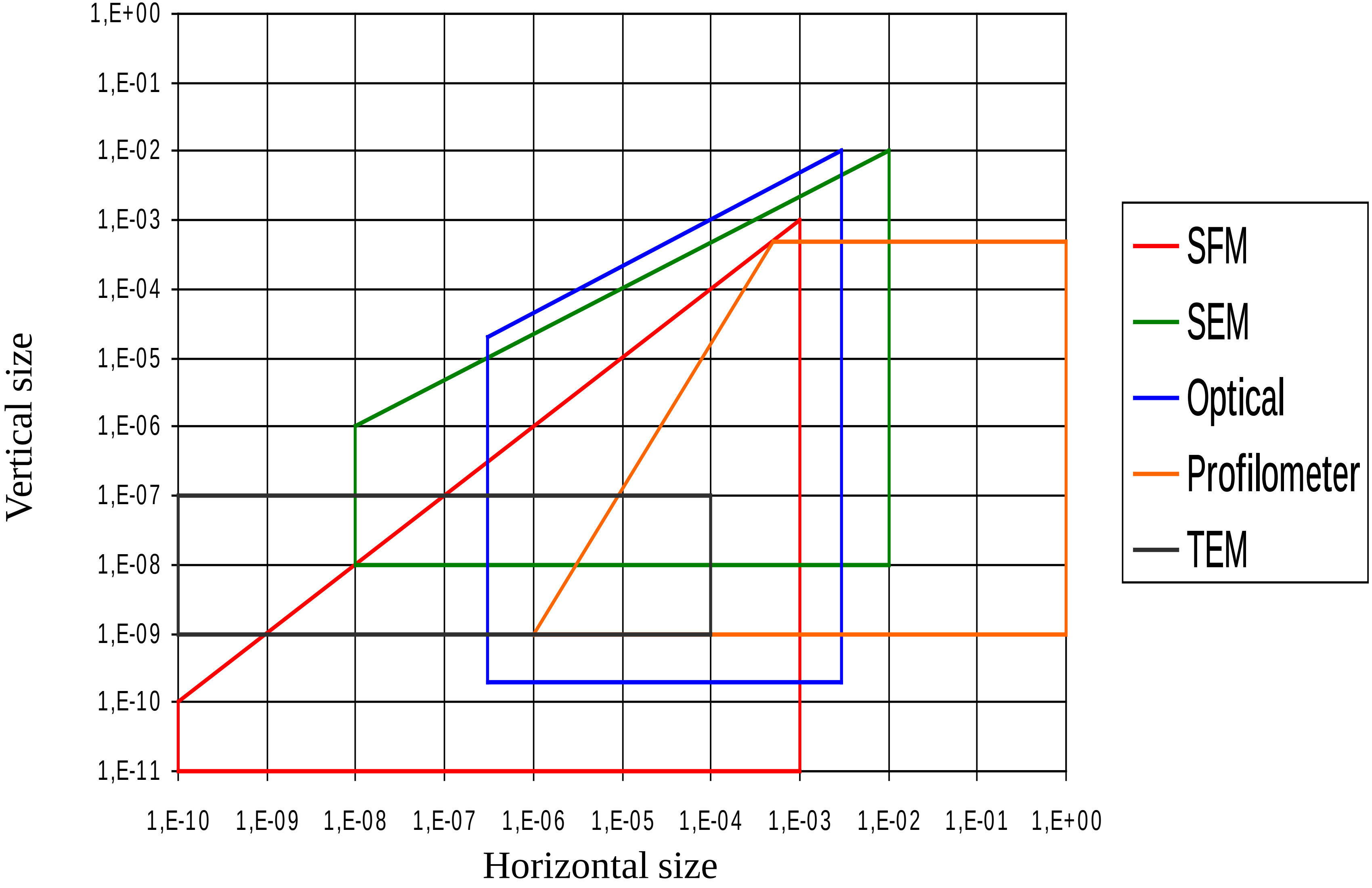


G. Binnig
öffnet
Fenster

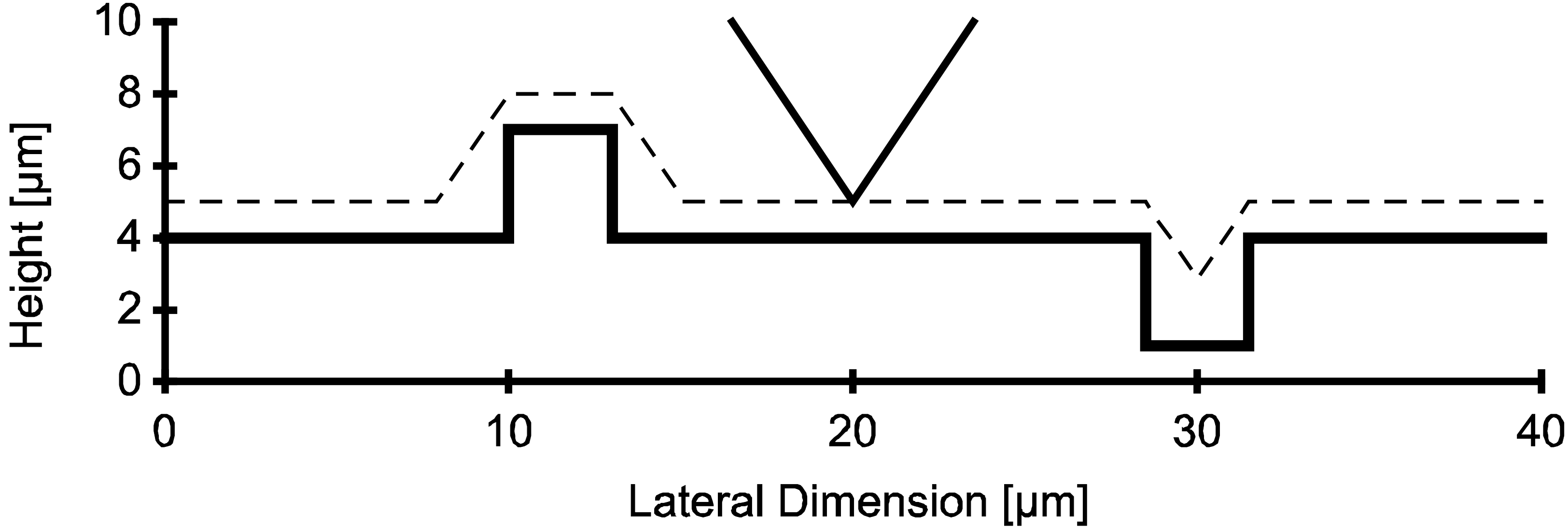
0,5 nm/div

STM, AFM: Auflösung Geräte

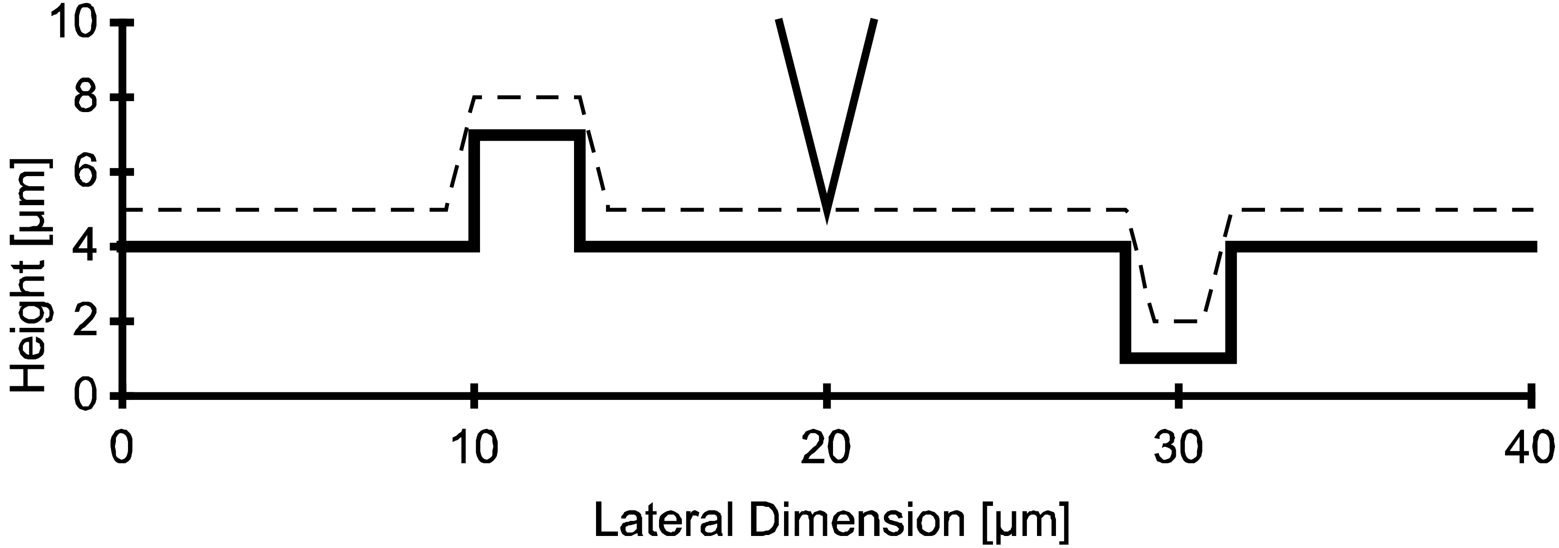
Microscope resolution



What do you „see“ with a scanning probe microscope?

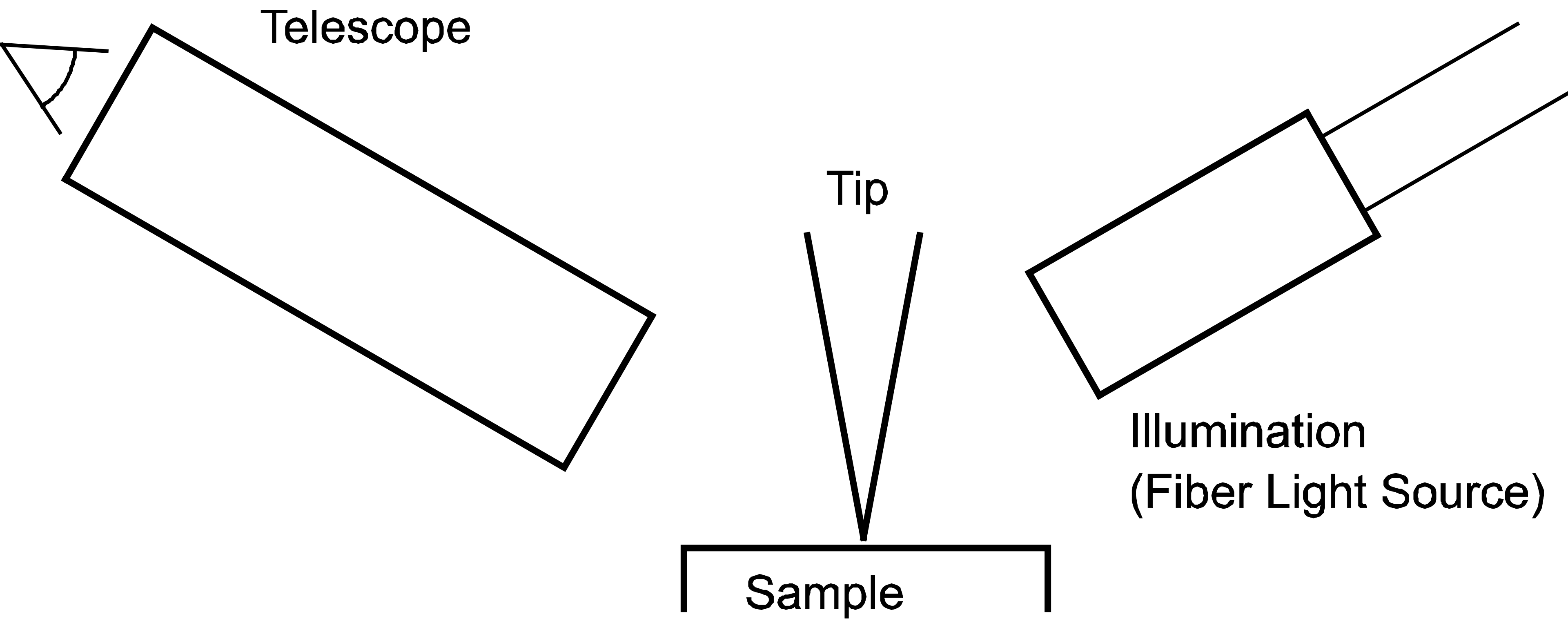


a)

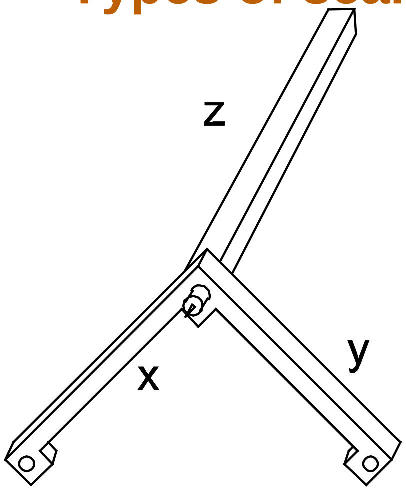


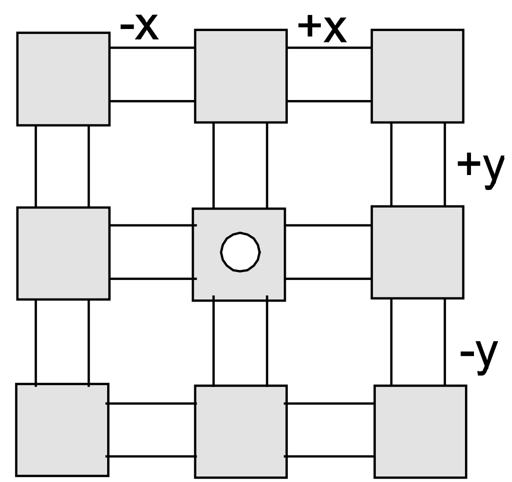
b)

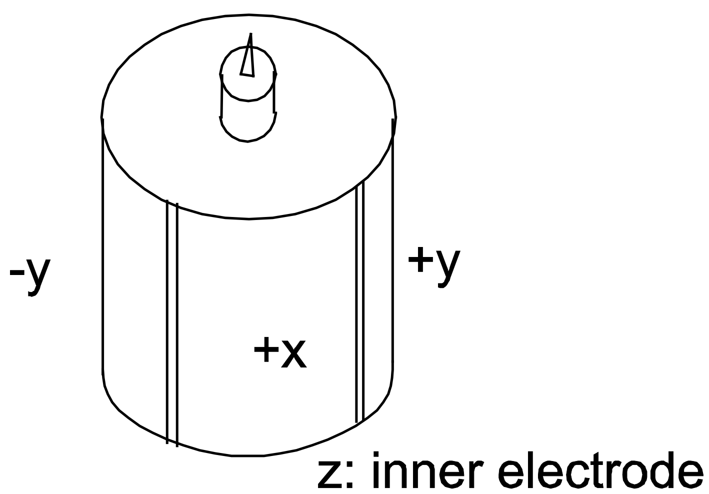
Approaching the Tip

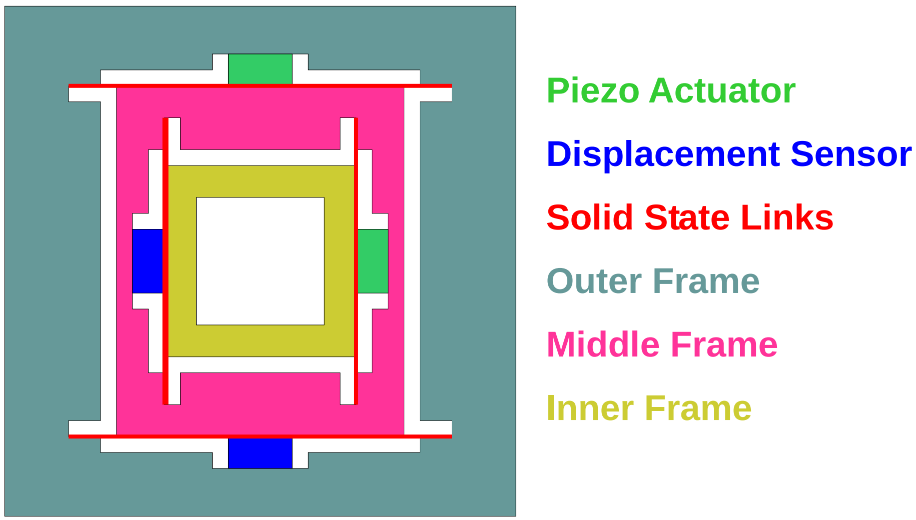


Types of scanners

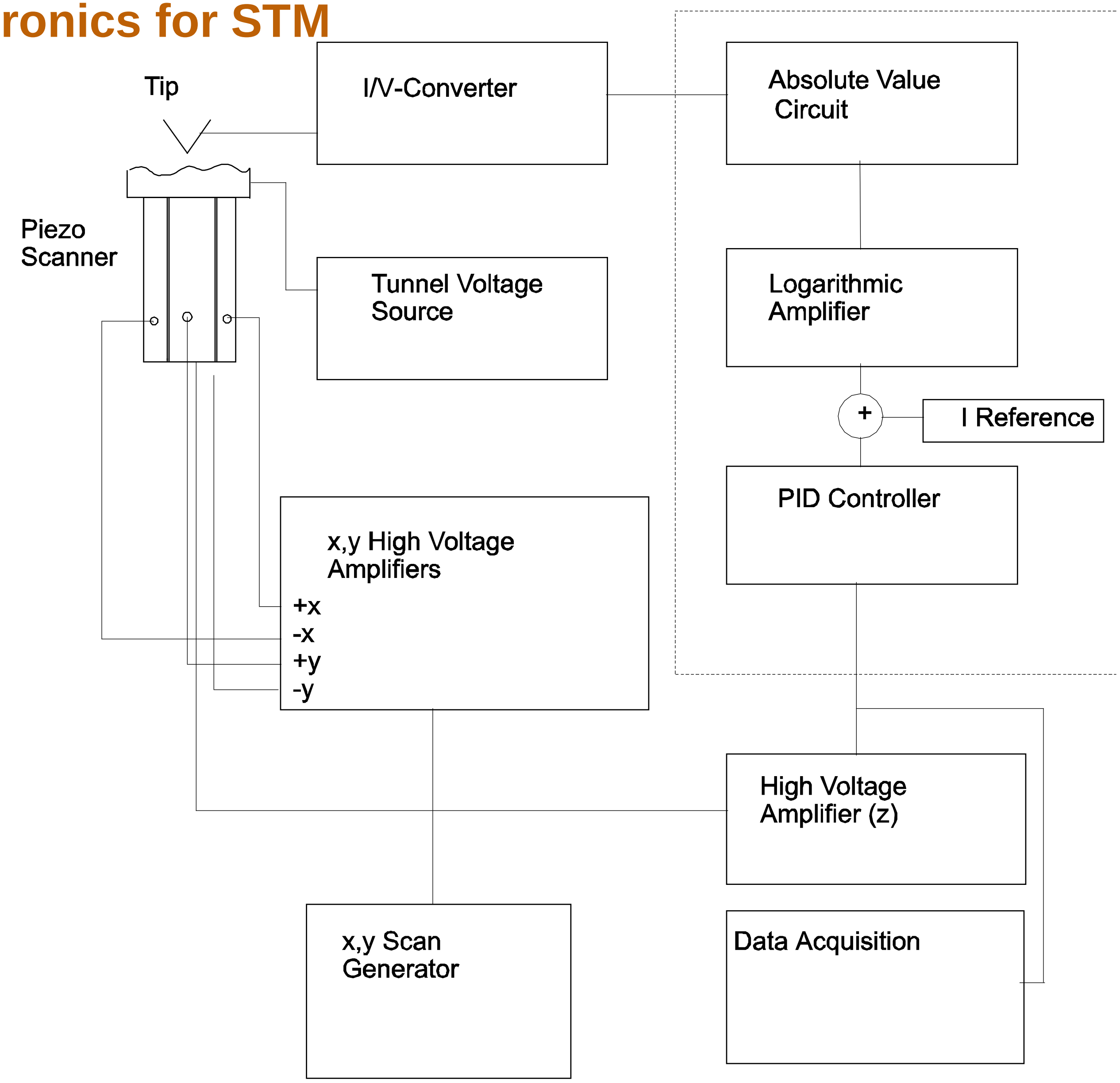




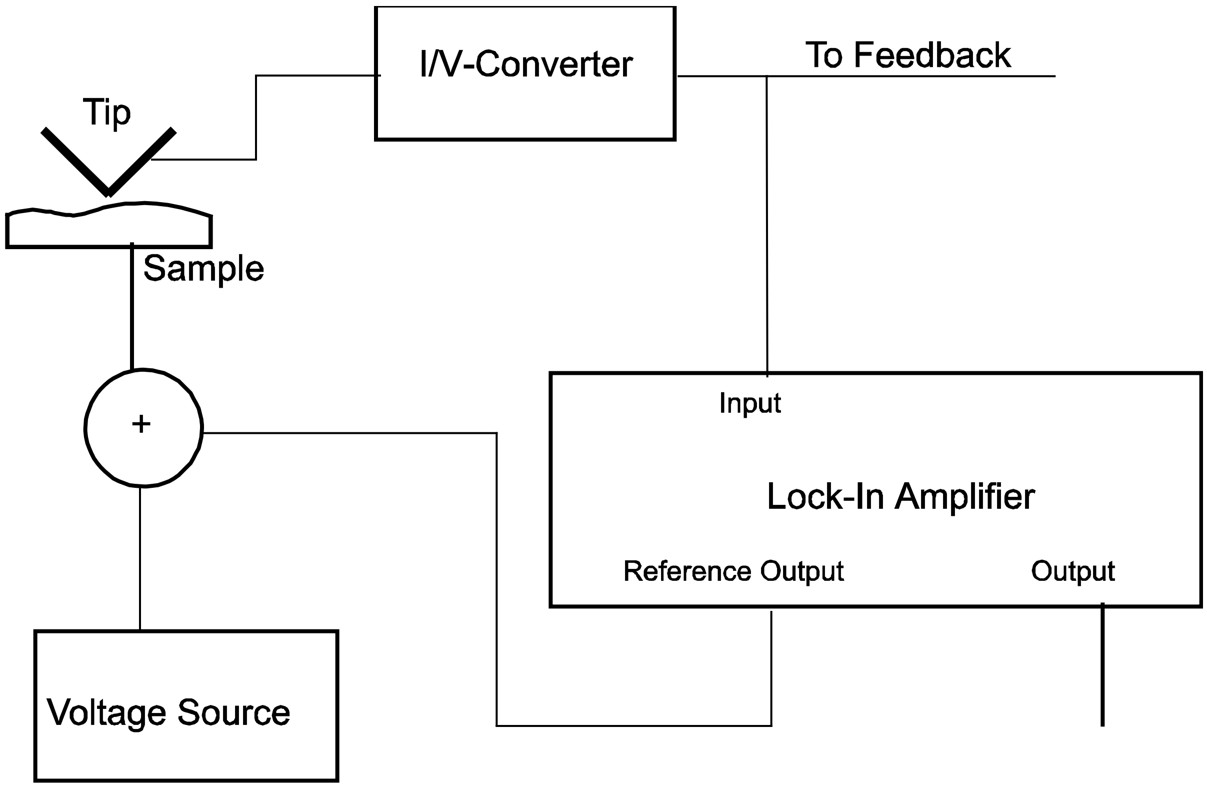




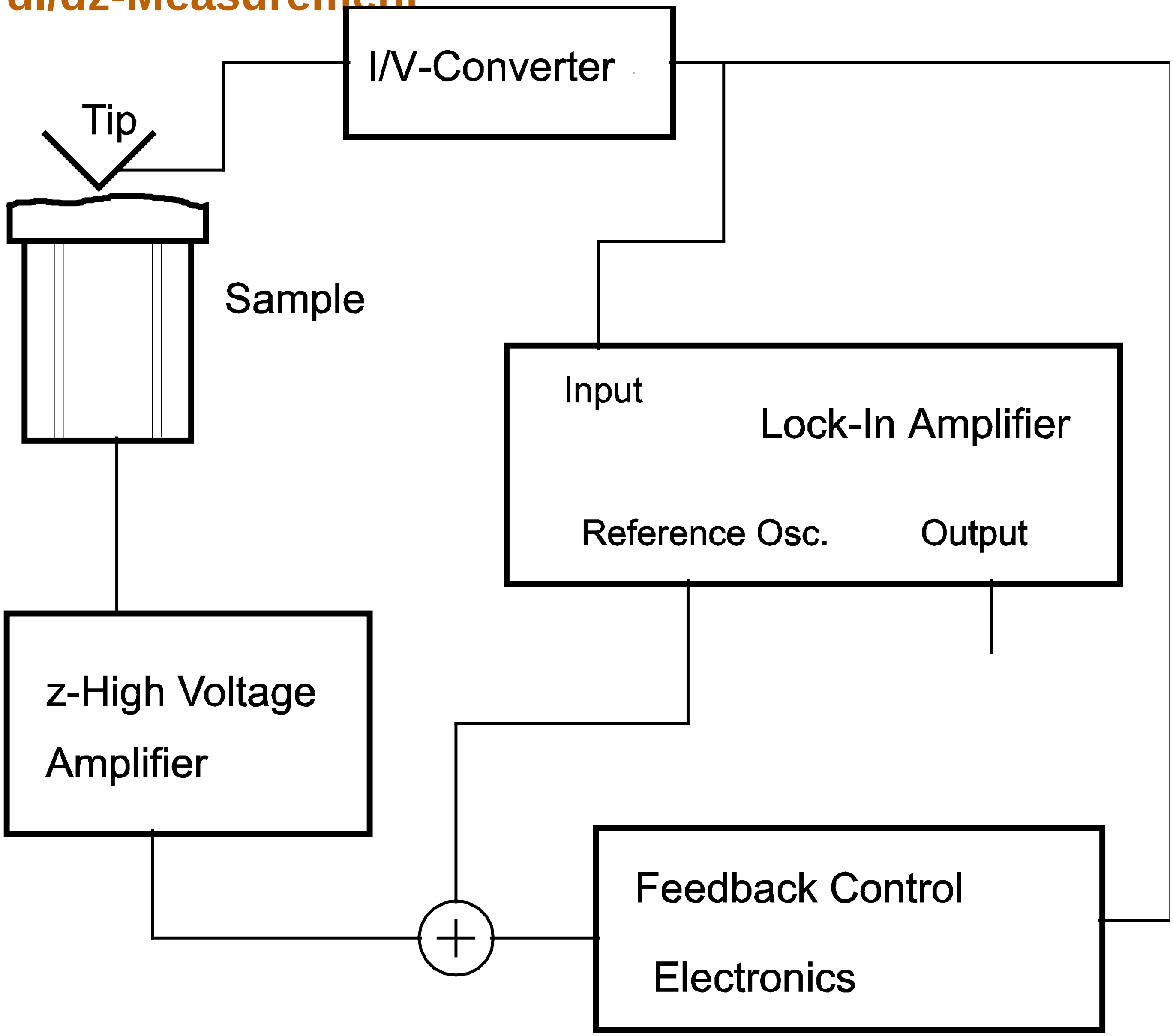
Electronics for STM



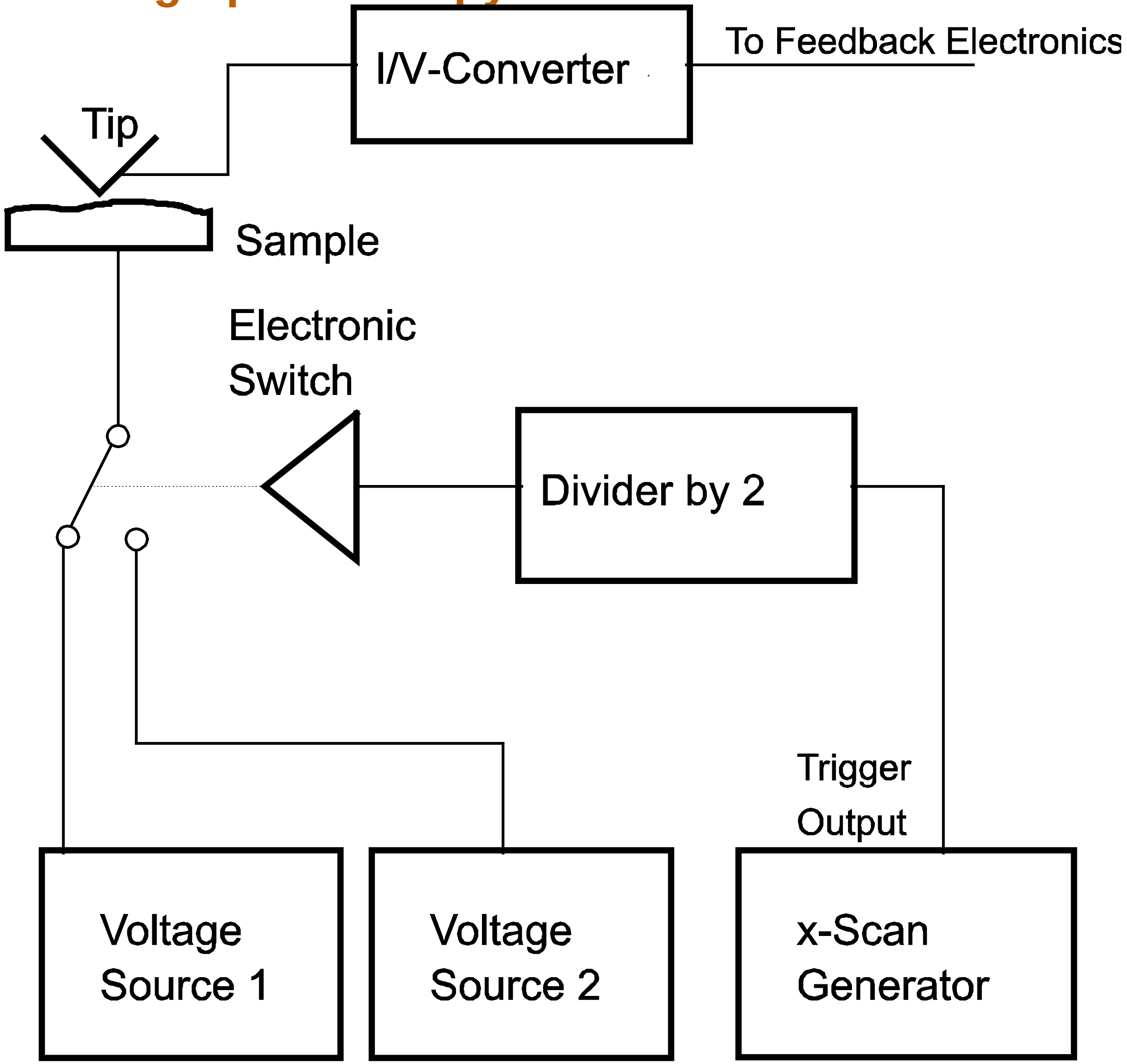
dI/dV-Spectroscopy



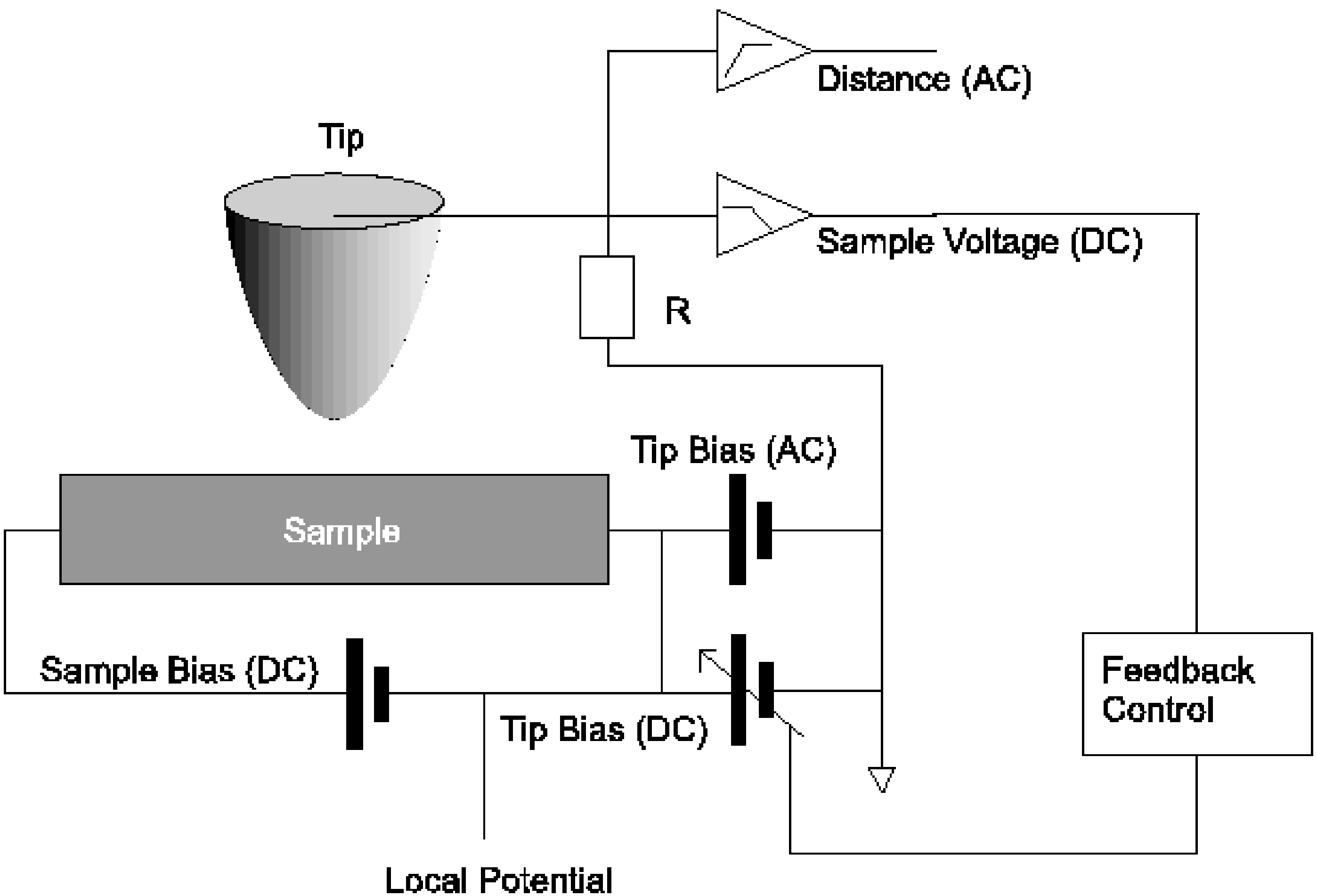
dI/dz-Measurement



Tunneling Spectroscopy



STM-Potentiometry



A voltage is applied along the sample surface by the voltage source (Sample Bias). The distance between the tip and the sample is measured with a small AC voltage. The DC-current is nulled by the feedback loop controlling the DC-portion of the tip bias voltage. The voltage at the tip bias (DC)-voltage source is equal to the local potential on the sample.

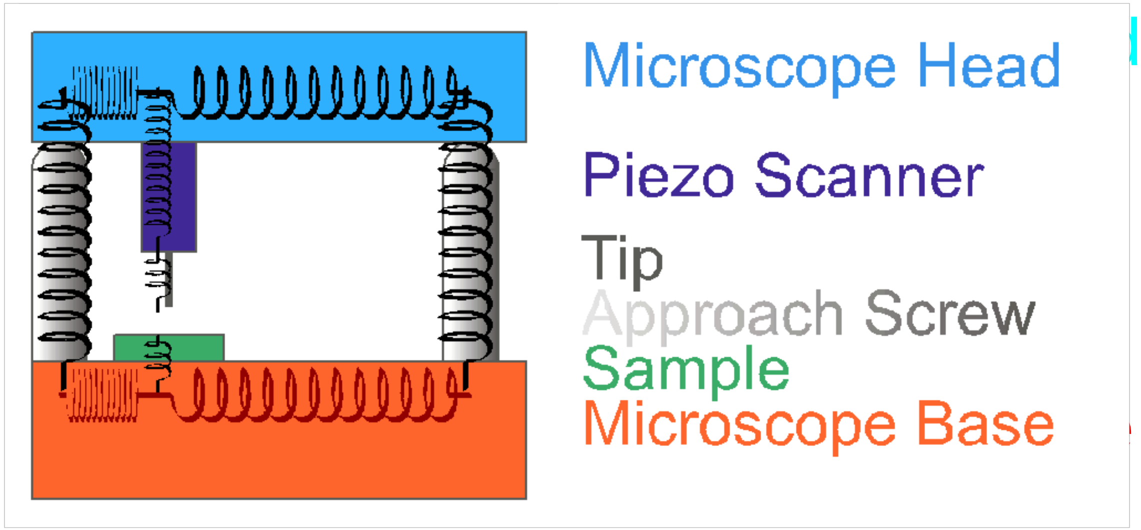
Scanning Tunneling Potentiometry

[redacted] top part shows the local
[redacted]ential on the sample, a MIM
[redacted]cture. The bottom part of the
[redacted]re is the corresponding
[redacted]ography. The image size is
[redacted] nm x 25 nm.

[redacted]ernational Business
[redacted]chines Corporation 1986)

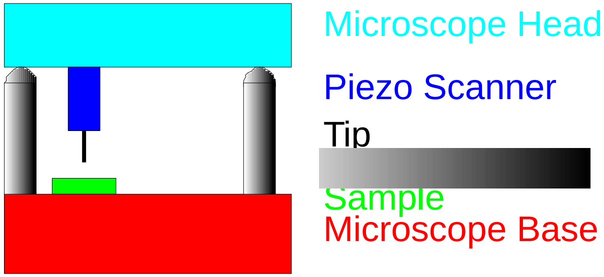
STM, AFM
und die Umgebung

Schematic Design of a Scanning Probe Microscope



Microscope modeled as springs:

Idealized View



The microscope is no rigid body

External vibrations disturb the measurement

(sound, buildings, equipment)

Vibrations: Some equations (a reminder)

Resonance frequency (lumped mass-spring-system)

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

k is the spring constant, m_{eff} the effective mass

A cantilevered beam has the spring constant

$$k = \frac{3EI}{l^3}$$

if the force is applied to the end of the beam

I is the moment of inertia, which is for a rectangular beam

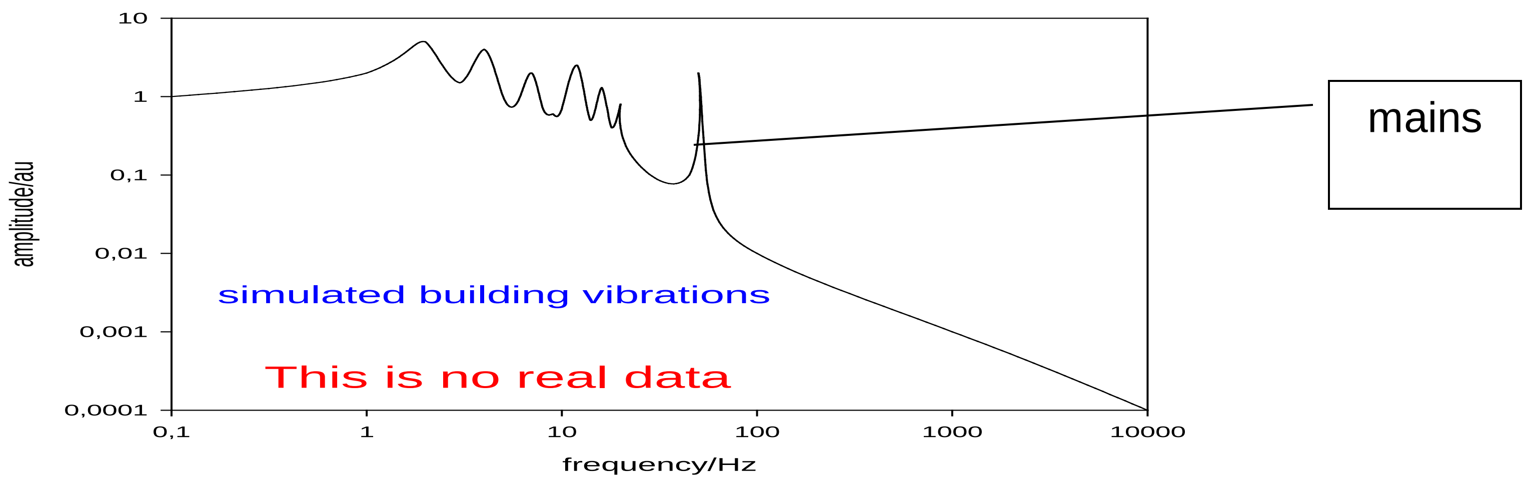
$$I = \frac{bh^3}{12}$$

Consequences

Any scanning probe microscope (in fact: any instrument) is a many degree of freedom oscillatory system

- These vibrations couple. Sum- and difference frequencies may also occur.

Any external vibration may couple to the microscope



If the relative position between tip and sample is changed by a vibration mode, then imaging is not possible

Vibration modes which do not affect the relative position of tip and sample are not important.

Possible strategies

The resulting frequency is

$$f = \frac{1}{2\pi}\sqrt{\frac{Ebh^3}{4\ell^3 m_{eff}}} = \frac{1}{2\pi}\sqrt{\frac{Ebh^3}{4\ell^3 (\alpha m)}}$$

0<α<1 is a factor converting mass to effective mass

$$f = \beta\sqrt{\frac{Ebh^3}{\ell^3 m}} = \beta\sqrt{\frac{Ebh^3}{\ell^3 (\rho \ell b h)}} = \beta\sqrt{\frac{E}{\rho}}\frac{h}{\ell^2}$$

where β is a prefactor close to unity

Build the microscope as close to a sphere as possible
Avoid long slender structures

Why are beat frequencies bad?

The tunneling current is given by

$$I \approx I_0 \exp\left(-\frac{s}{\Lambda}\right)$$

where Λ is the characteristic decay length of order 0.1 nm

Assume that

$$s = s_0 + s_1 \cos(\omega_1 t) + s_2 \cos(\omega_2 t)$$

We have then

$$I \approx I_0 \exp\left(-\frac{s_0 + s_1 \cos(\omega_1 t) + s_2 \cos(\omega_2 t)}{\Lambda}\right)$$

We approximate to second order

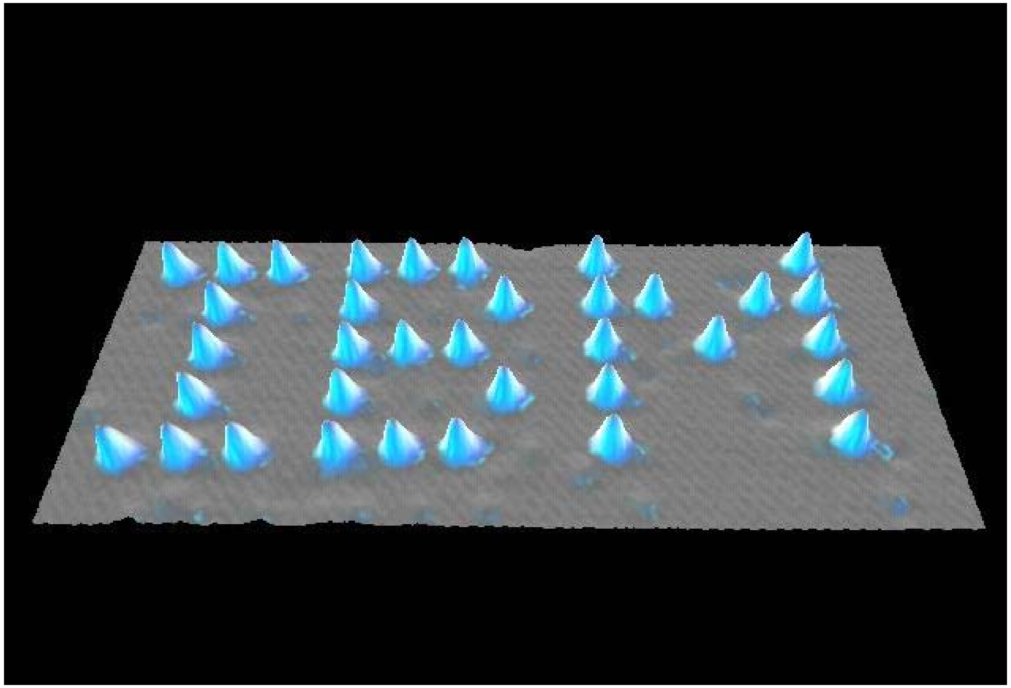
$$e^x = 1 + x + \frac{x^2}{2!} + O(x^3)$$

If we plug in *s* into the quadratic term, we will obtain terms at $\omega_1+\omega_2$ and at $\omega_1-\omega_2$.

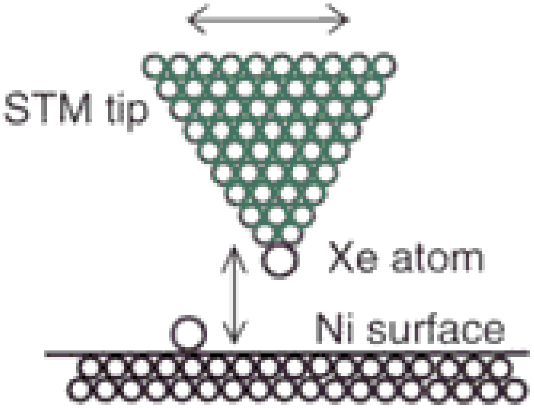
$\omega_1-\omega_2$ implies, that two resonances in the microscope close by can have disastrous consequences

STM, AFM Experimente

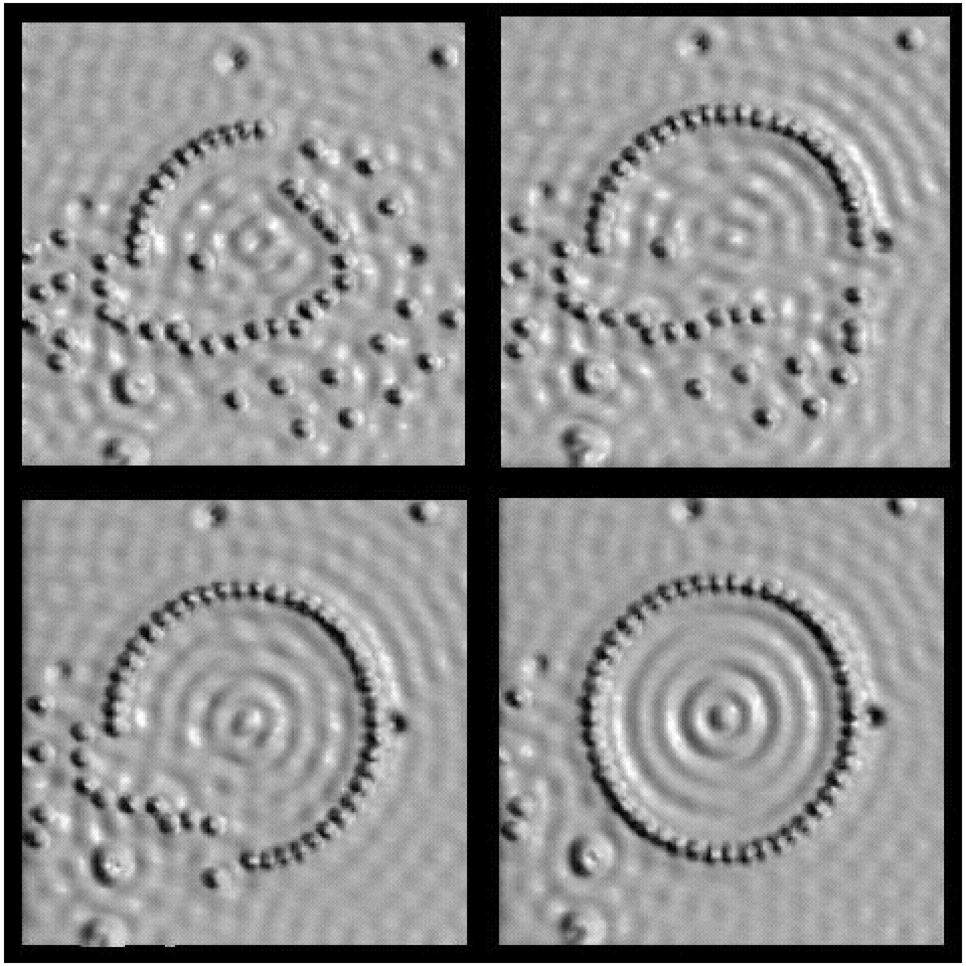
Eigler: Manipulation mit STM



Xenonatome werden mit der Tunnelspitze verschoben



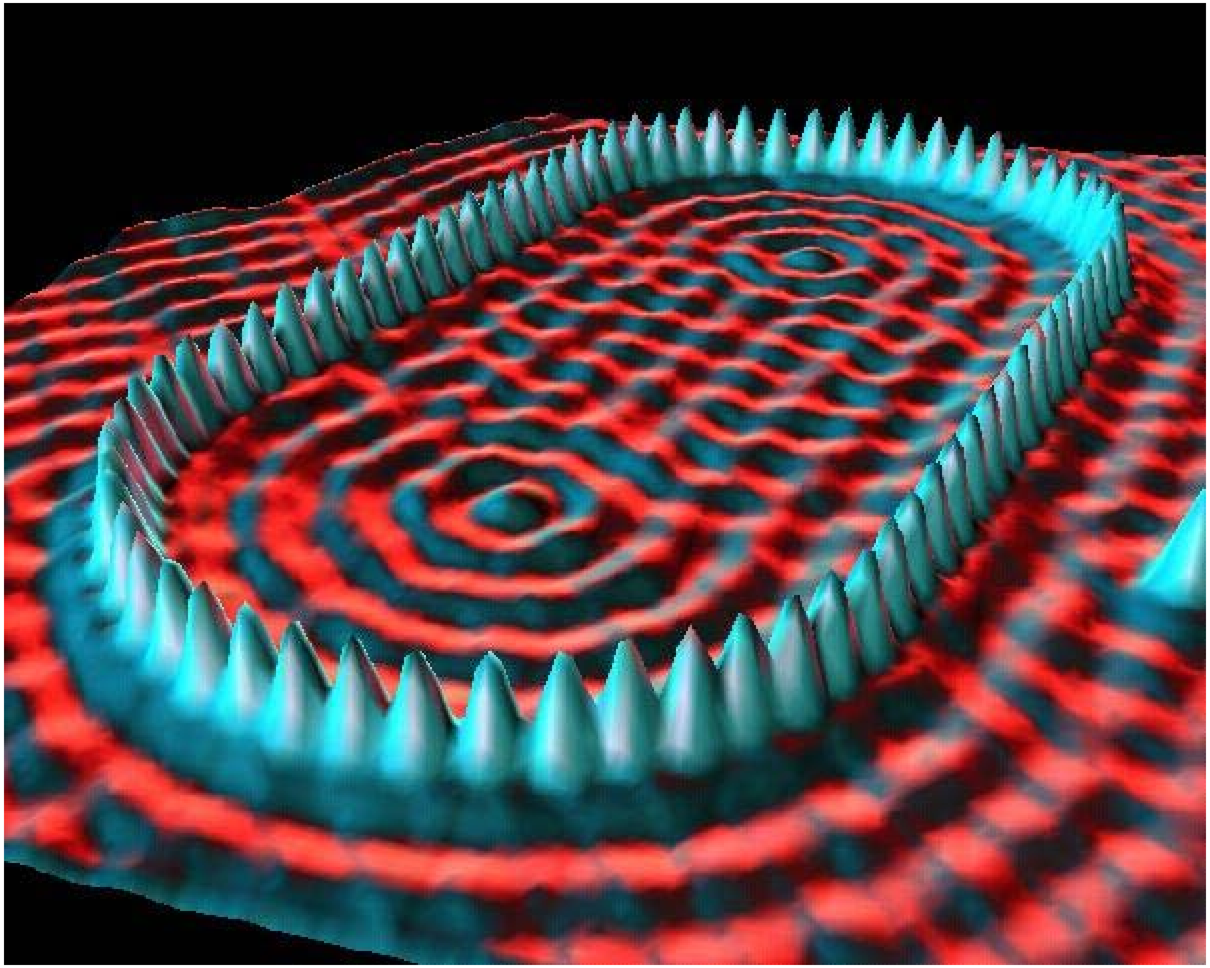
Eigler: Schritte bei der Manipulation



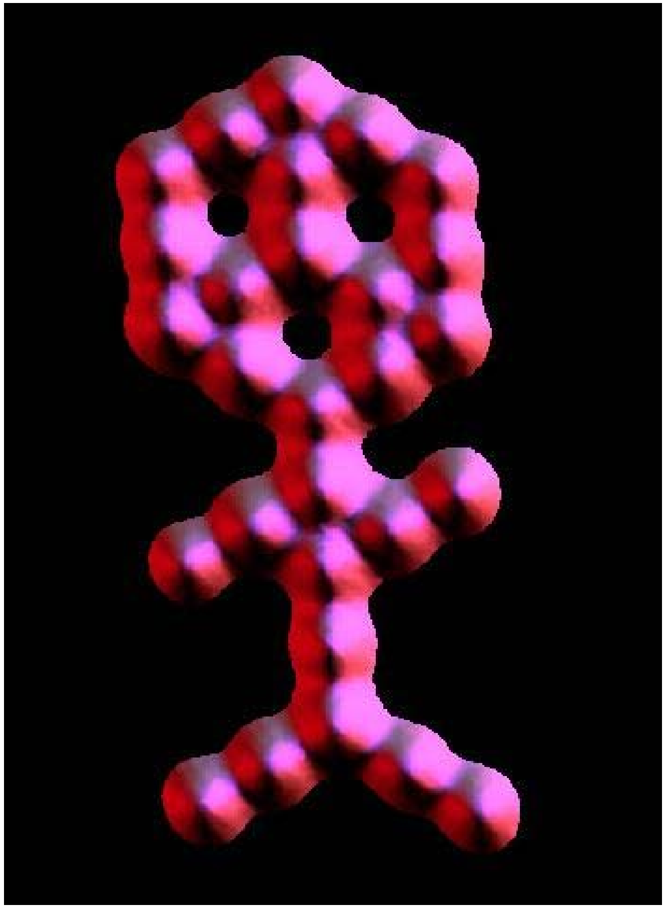
Eisenatome
auf Kupfer

Quanten-Stadium

Eisenatome
auf Kupfer



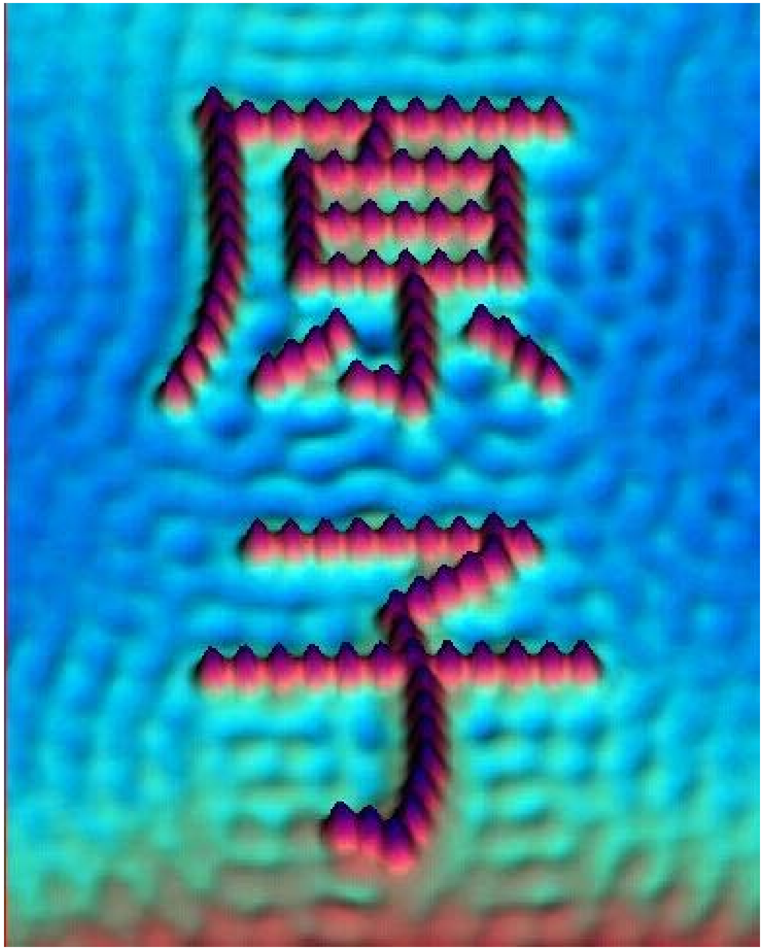
Titel : Carbon Monoxide Man
Medium : Kohlenmonoxid auf Platin (111)



Kommentar der „Künstler“:

The artist, Zeppenfeld, was known to go through playful moods, leaving behind a series of images in the lab notebooks, none of which were serious in nature. [Zeppenfeld & Eigler]

*Titel: **Atom***
*Medium: **Fe auf Kupfer (111)***

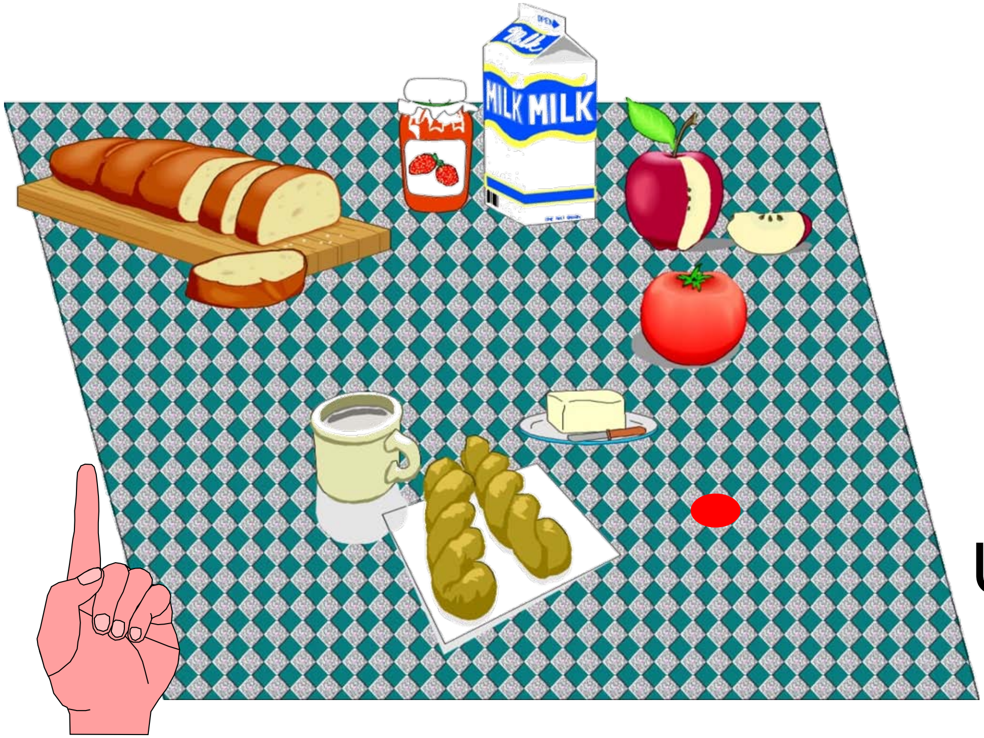


Kommentar der „Künstler“:

The Kanji characters for "atom." The literal translation is something like "original child."
[Lutz & Eigler]

AFM: Geräte

Wie misst ein Rasterkraftmikroskop?

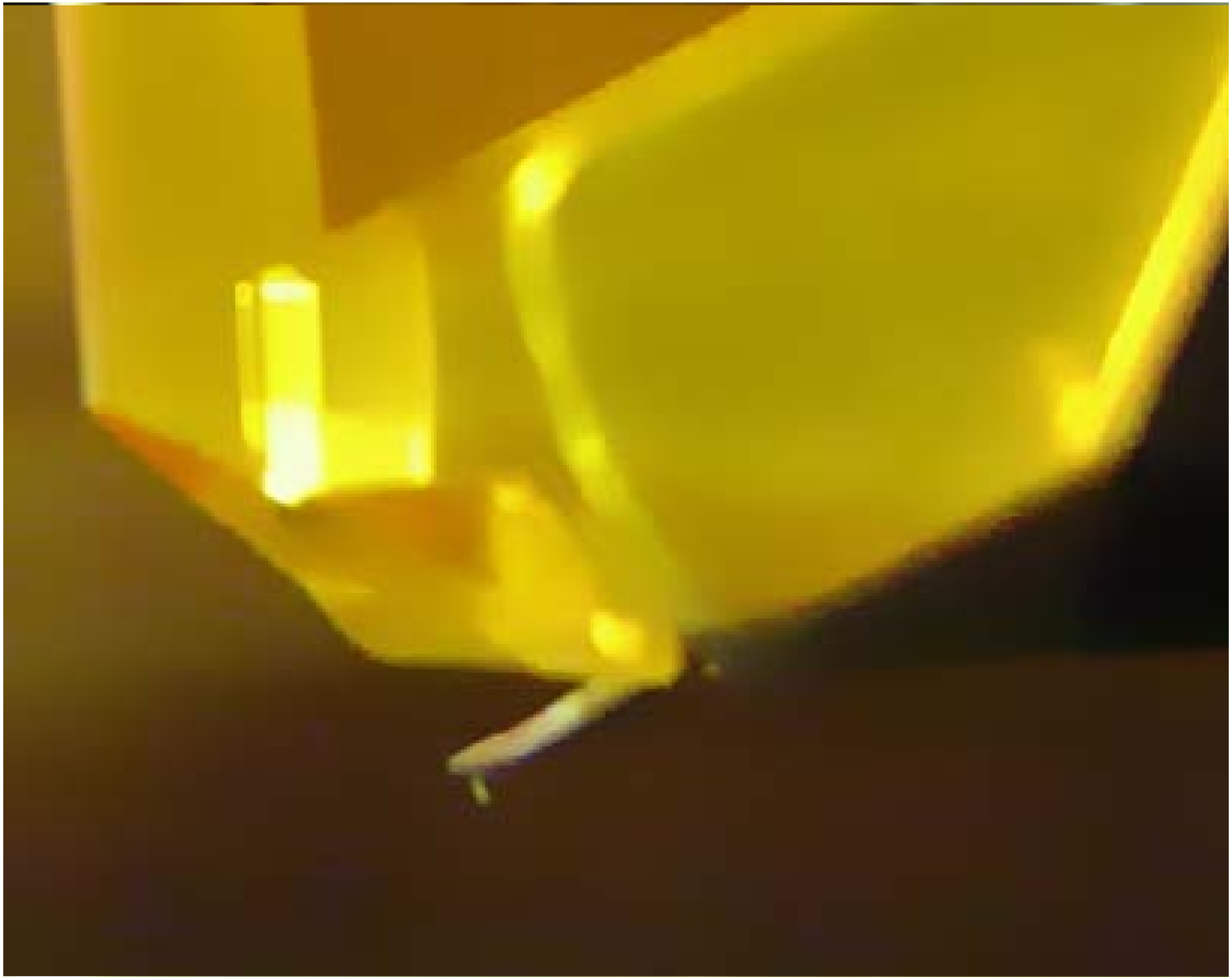


Im Dunkeln tastet man den Tisch mit der Hand ab

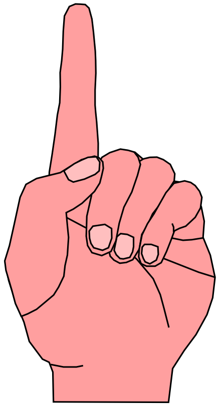
- hoch und runter
- hart und weich
- klebrig
- warm und kalt

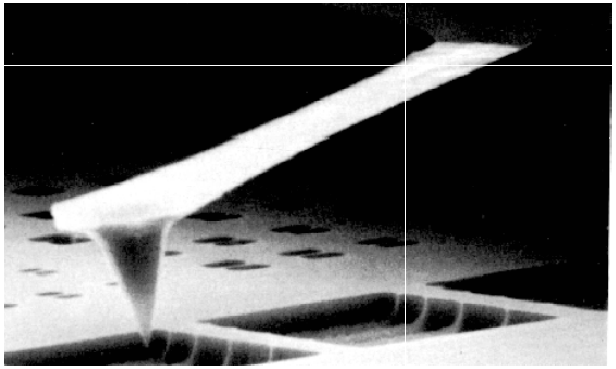
Unser Gehirn setzt das Bild zusammen

Plattenspielernadel



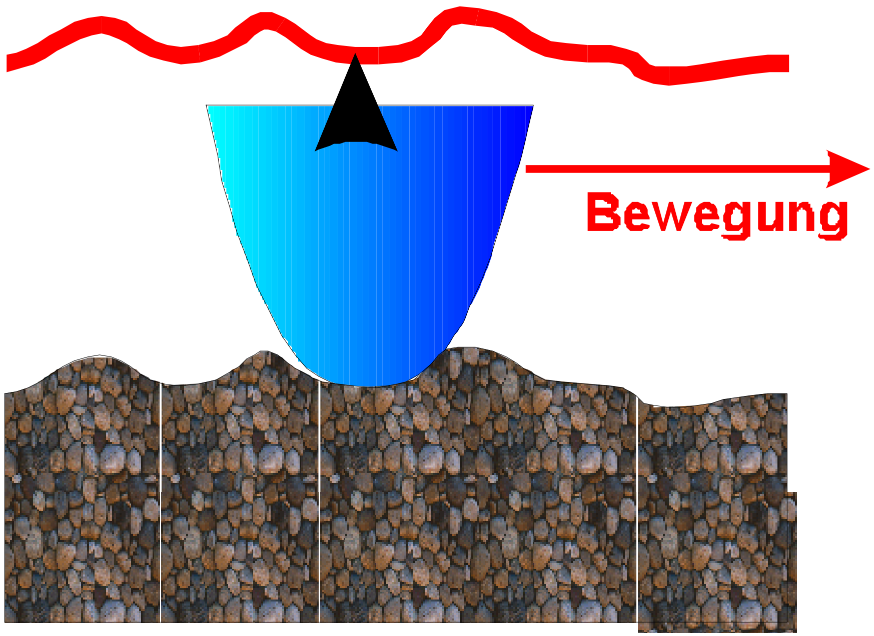
Kraftmessung: Sensor





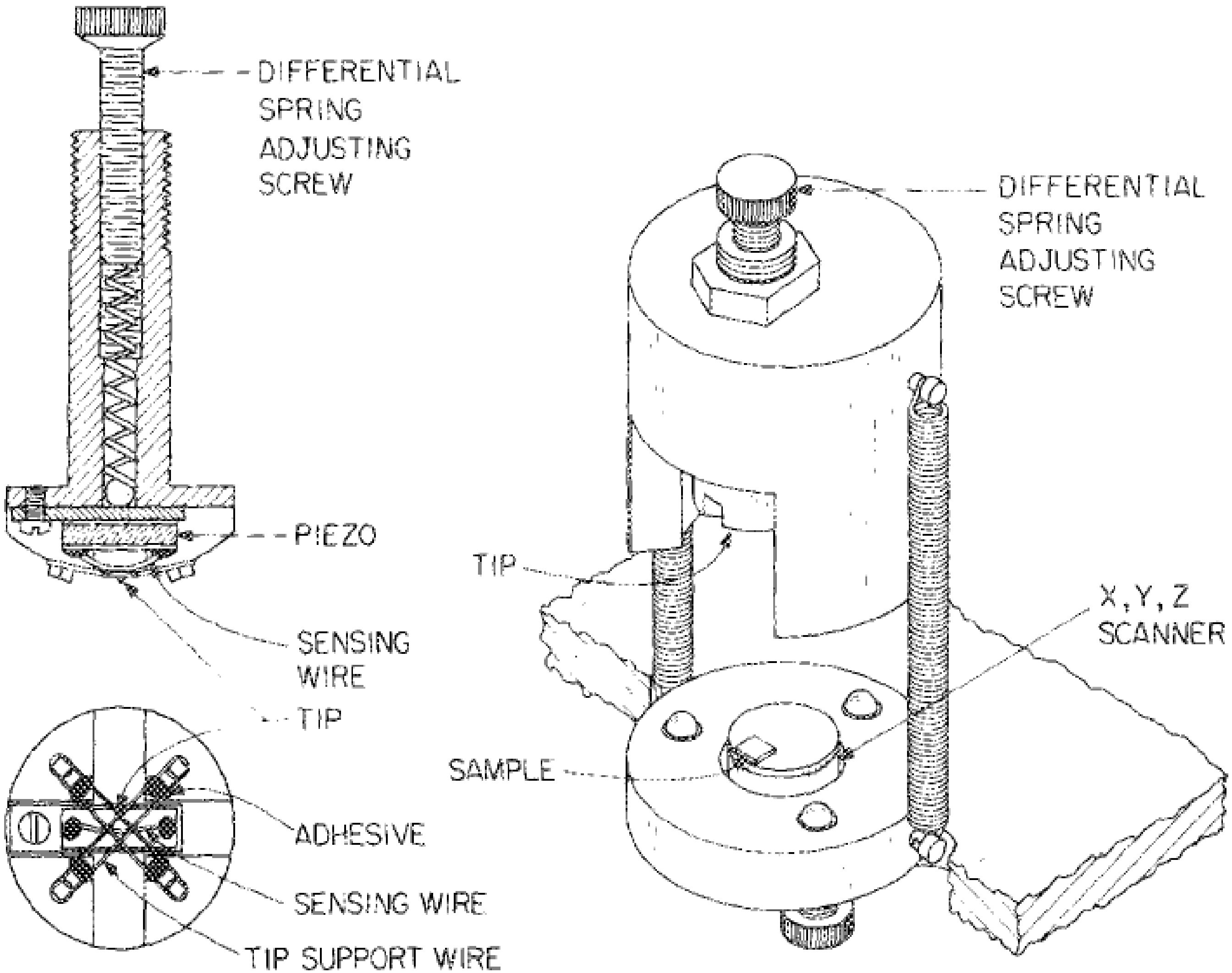
	Finger	Abtastnadel	Kraftmessbalken
Grösse:	10 cm	1 cm	100 µm
Tastkopf Ø:	1cm	20 µm	20 nm
Empfindlichkeit:	1 mN	1 µN	1 pN
Material:	Haut	Diamant	Silizium, Si_3N_4, Diamant

Messung von Profilen



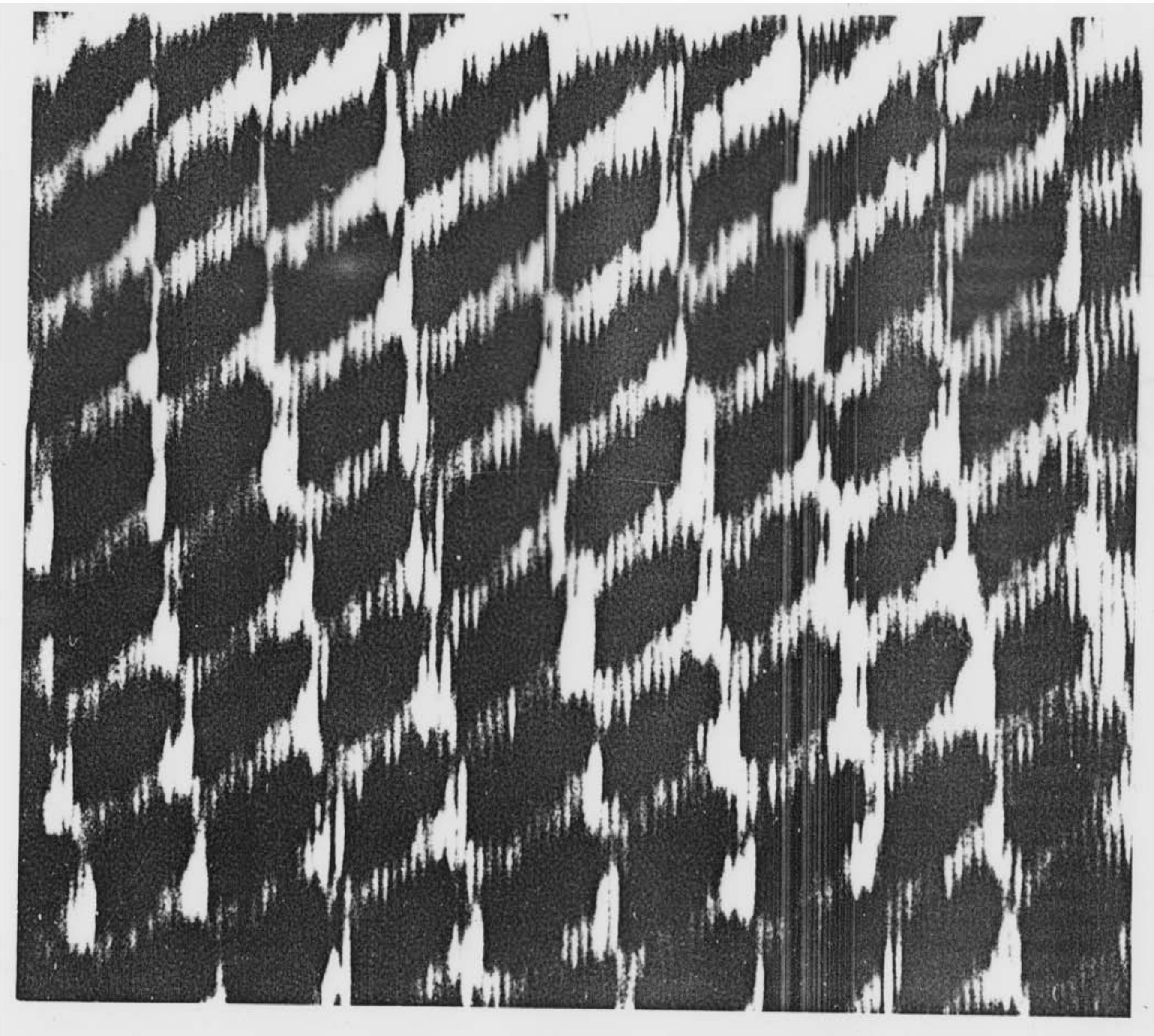
- Tastsonde wird mit konstanter Andruckkraft über die Oberfläche geführt
- Höhen werden gemessen und mit der jeweiligen Position gespeichert

Erstes AFM in Santa Barbara



O. Marti, B. Drake, and P. K. Hansma,, ***Applied Physics Letters*** **51**(7): 484-48

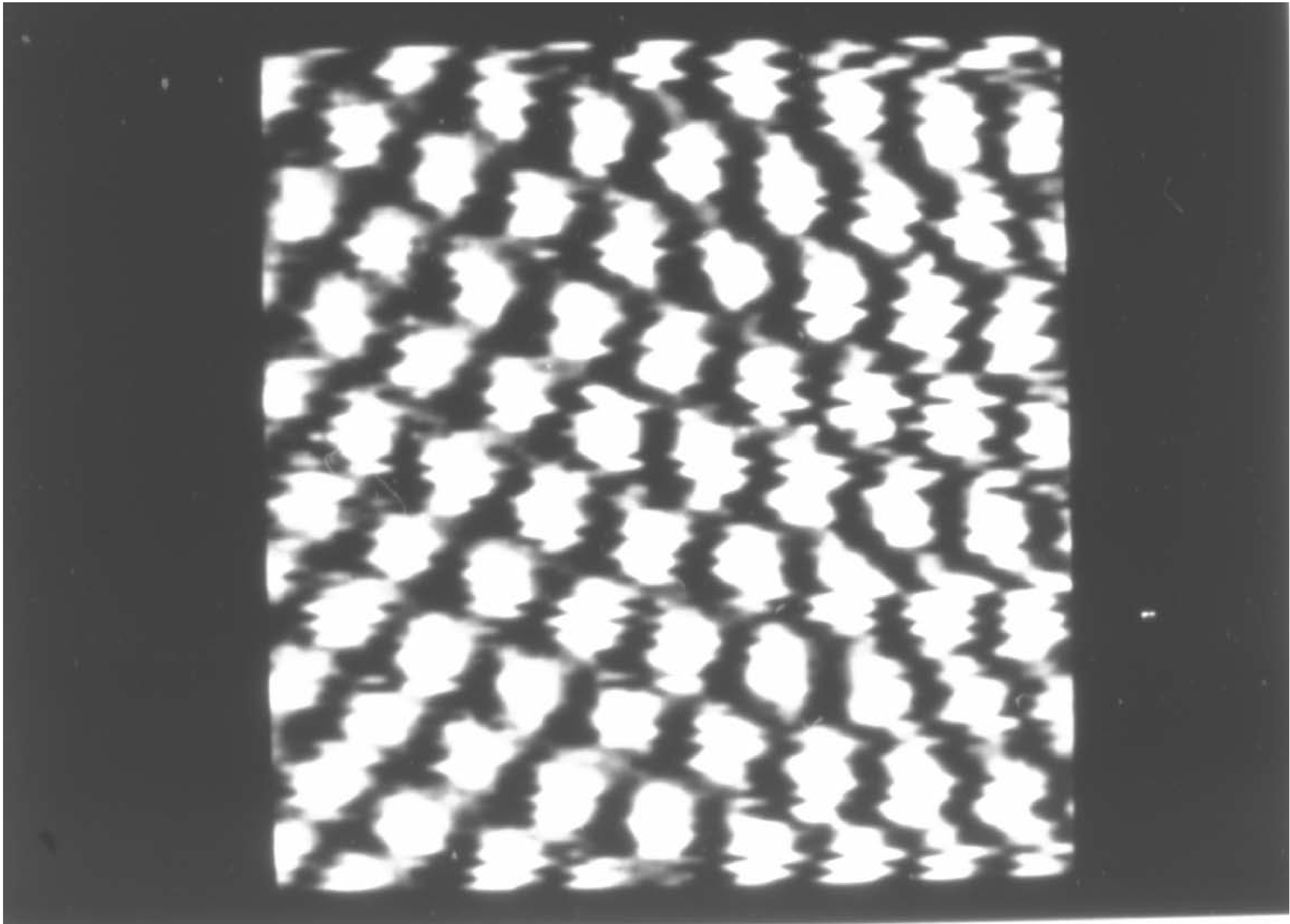
Graphit gemessen unter Flüssigkeiten 1987



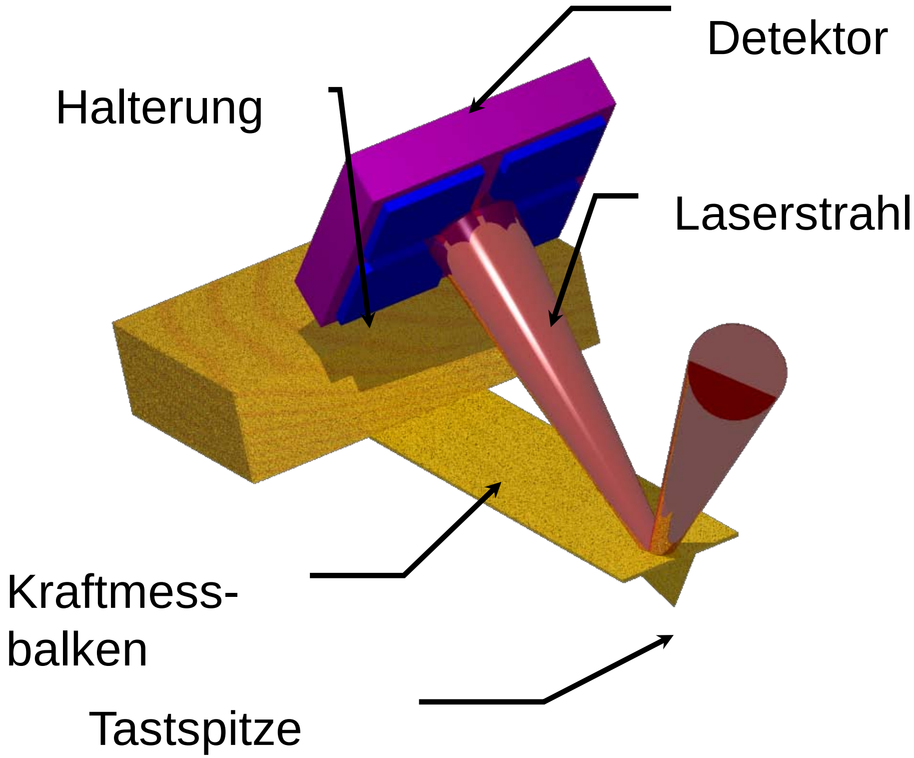
O. Marti, B. Drake, and P. K. Hansma,, ***Applied Physics Letters*** **51**(7): 484-486 (1987).

Graphit 1987

O. Marti, B. Drake, and P. K. Hansma,, ***Applied Physics Letters*** **51**(7): 484-486 (1987).



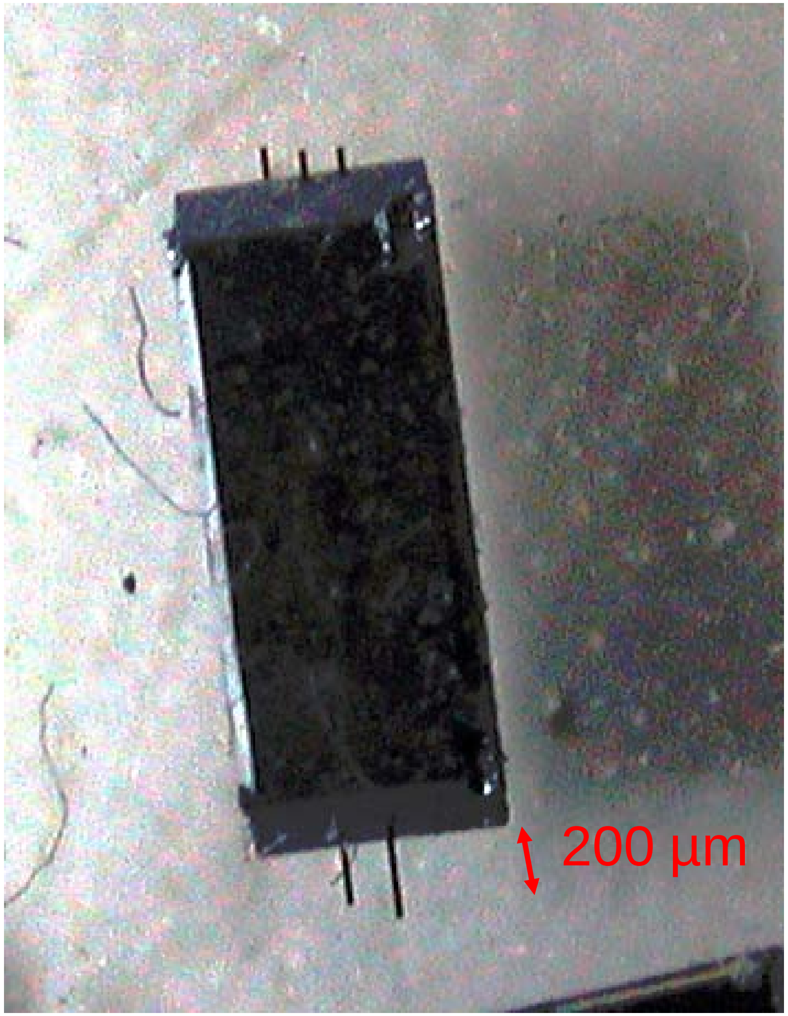
Kraftmessung: Detektion



Lichtzeigereffekt

- Detektion aus Entfernung
- Zwei Kräfte können gleichzeitig gemessen werden
- Elektronik ähnlich wie bei CD-Plattenspieler
- Problemlose Anwendung in fast allen Medien

AFM-Balken

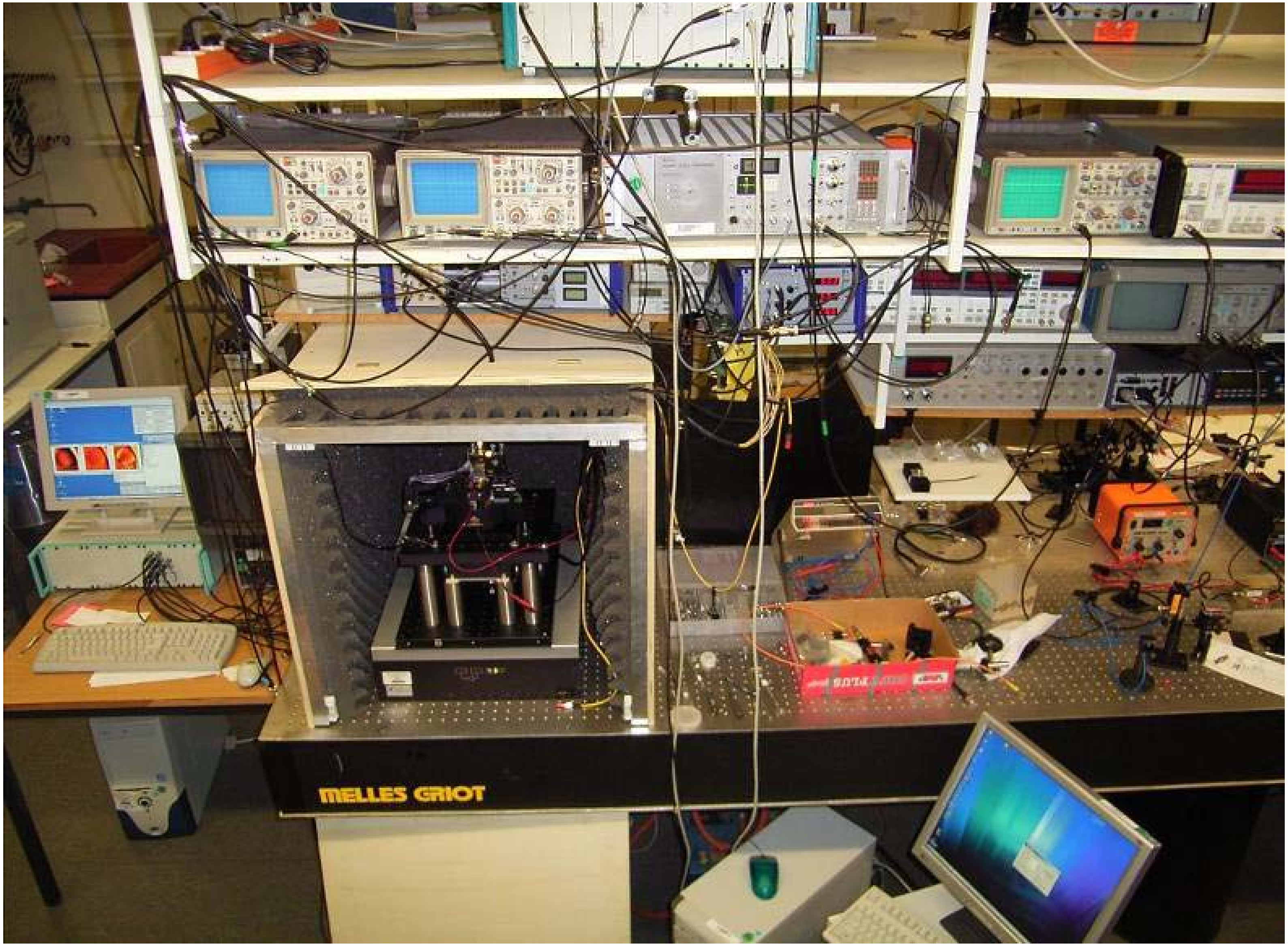


Material Silizium

Federkonstanten

- 0,01-100 N/m

Introduction: custom-built AFM



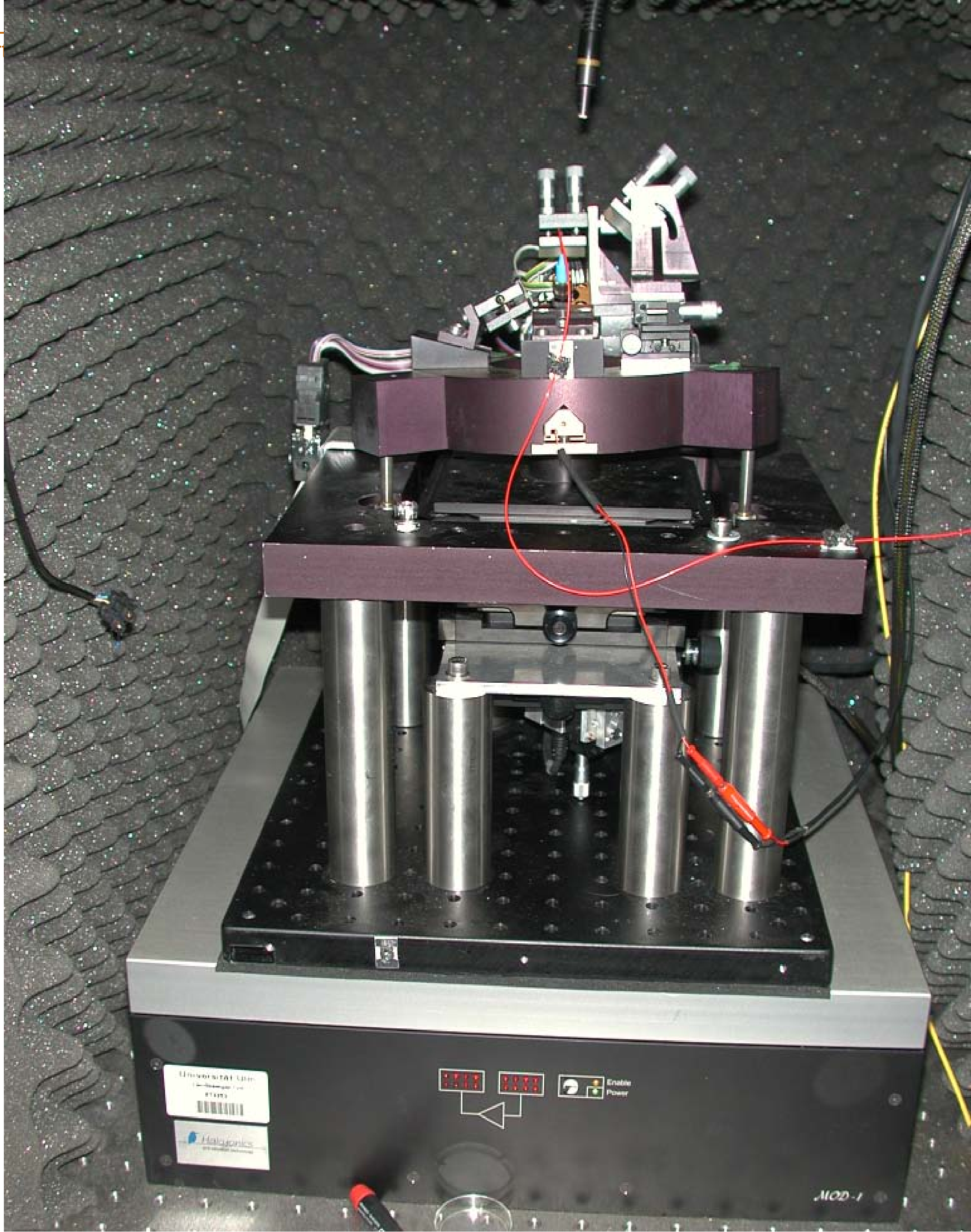
AFM

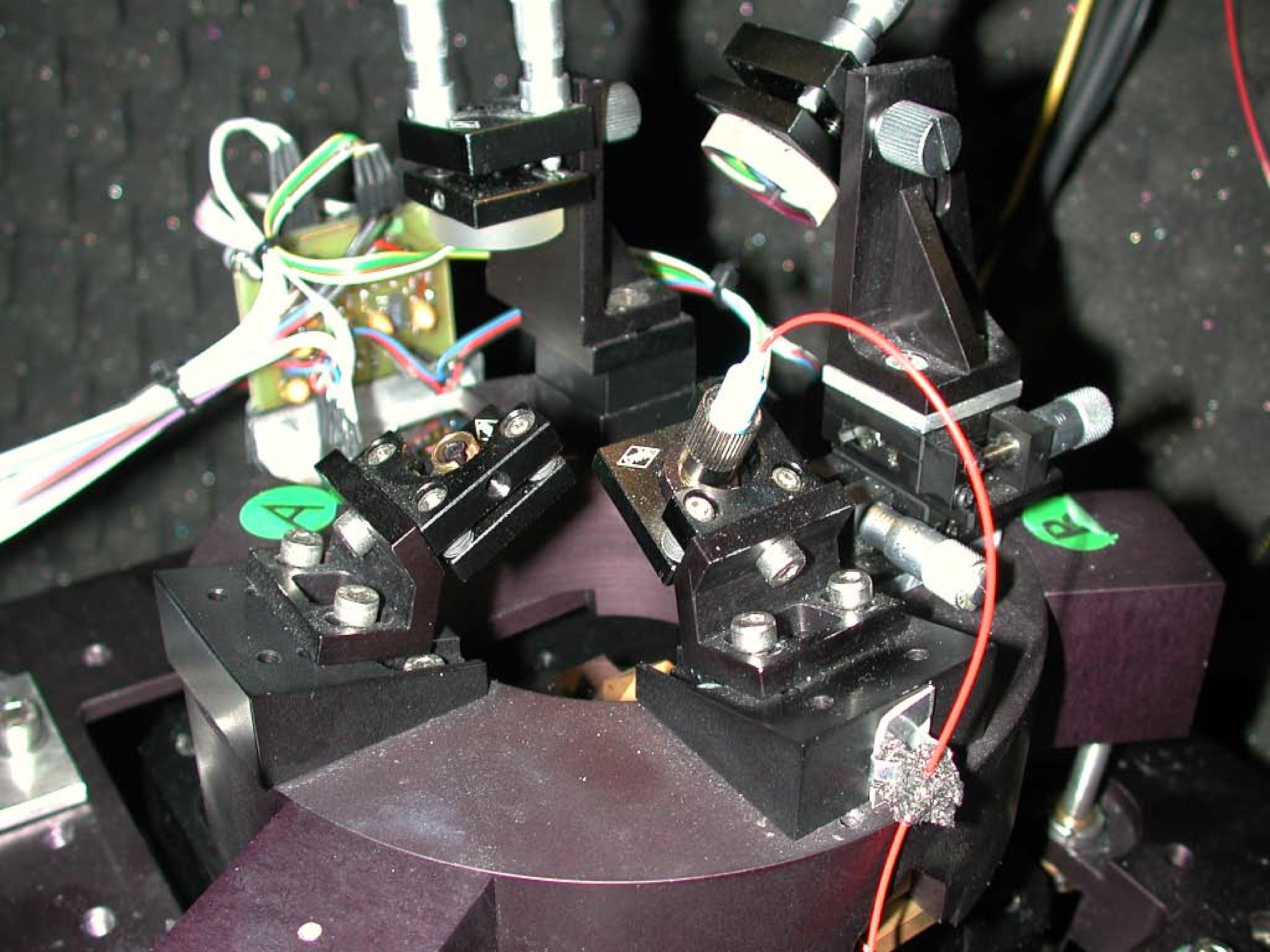
AFM

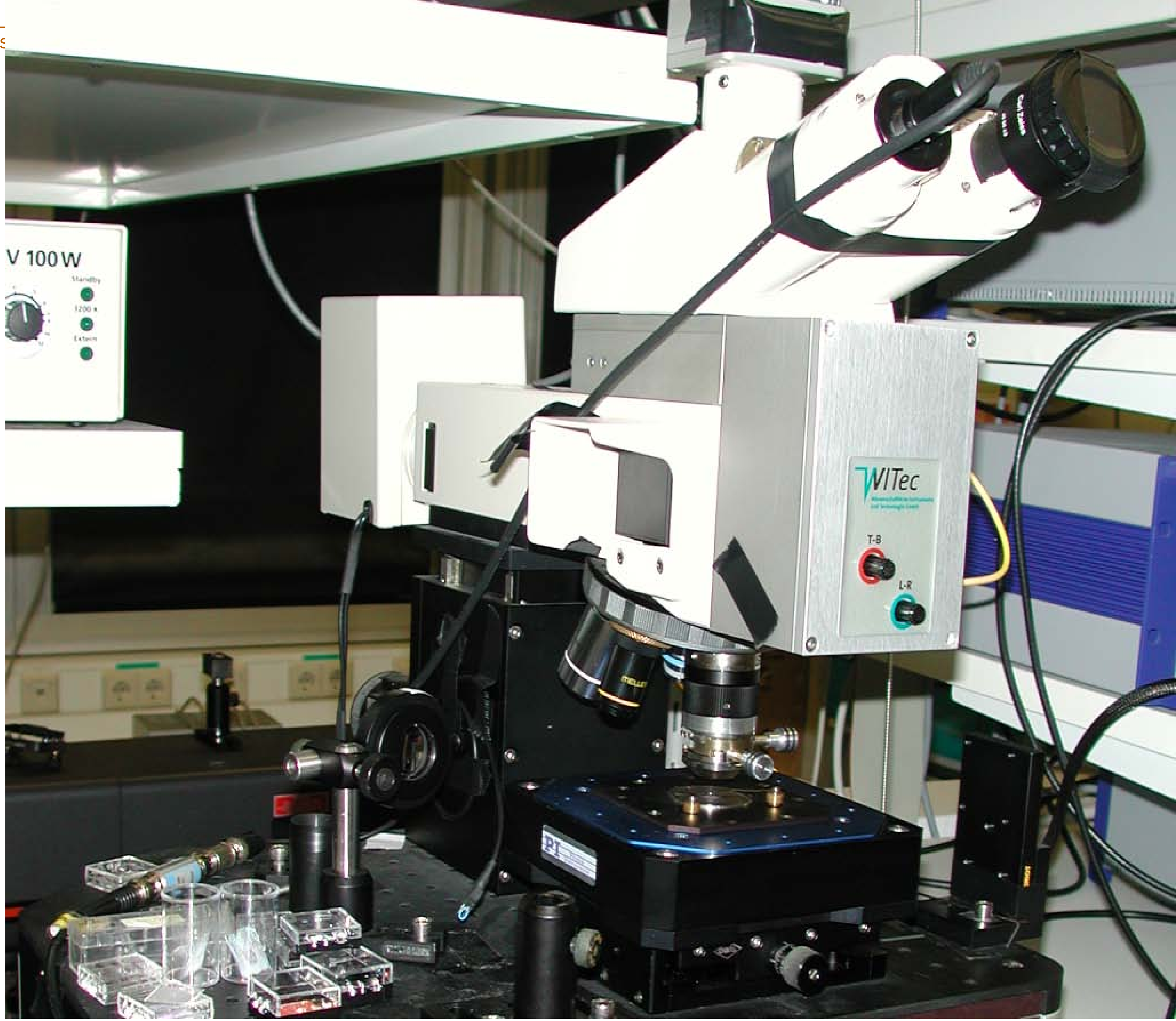
Kamera

Schallisolation

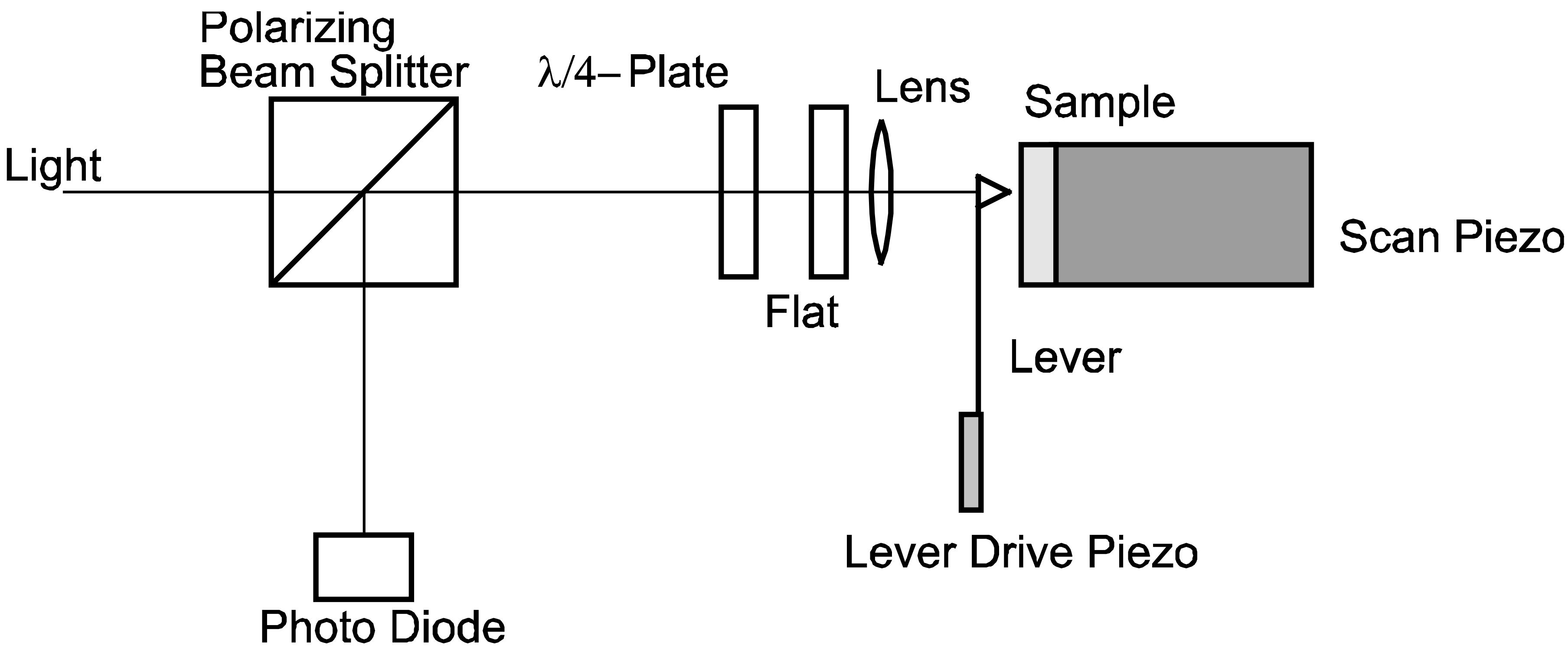
Vibrationsisolation



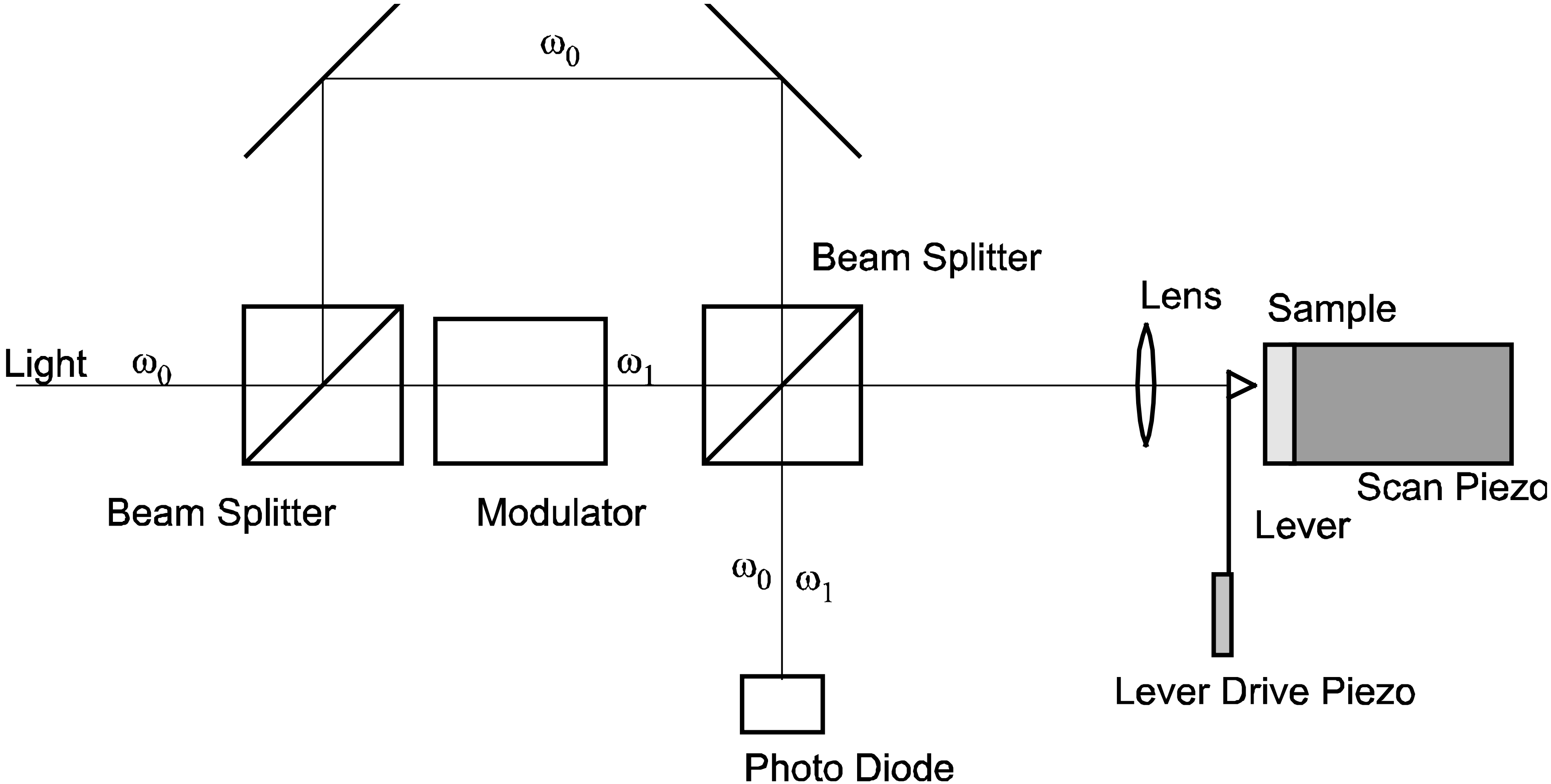

A
R


V 100 W
WITec
T-B
L-R

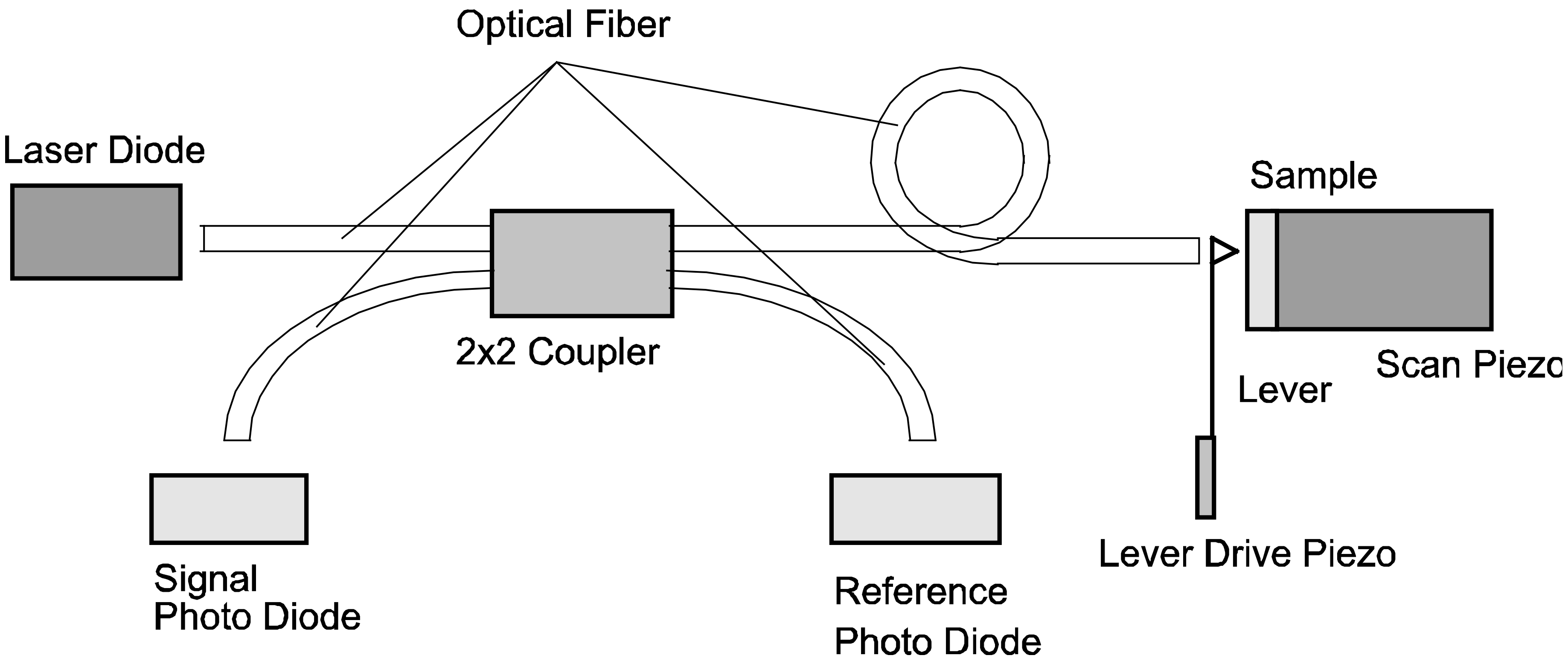
Interferometer-AFM



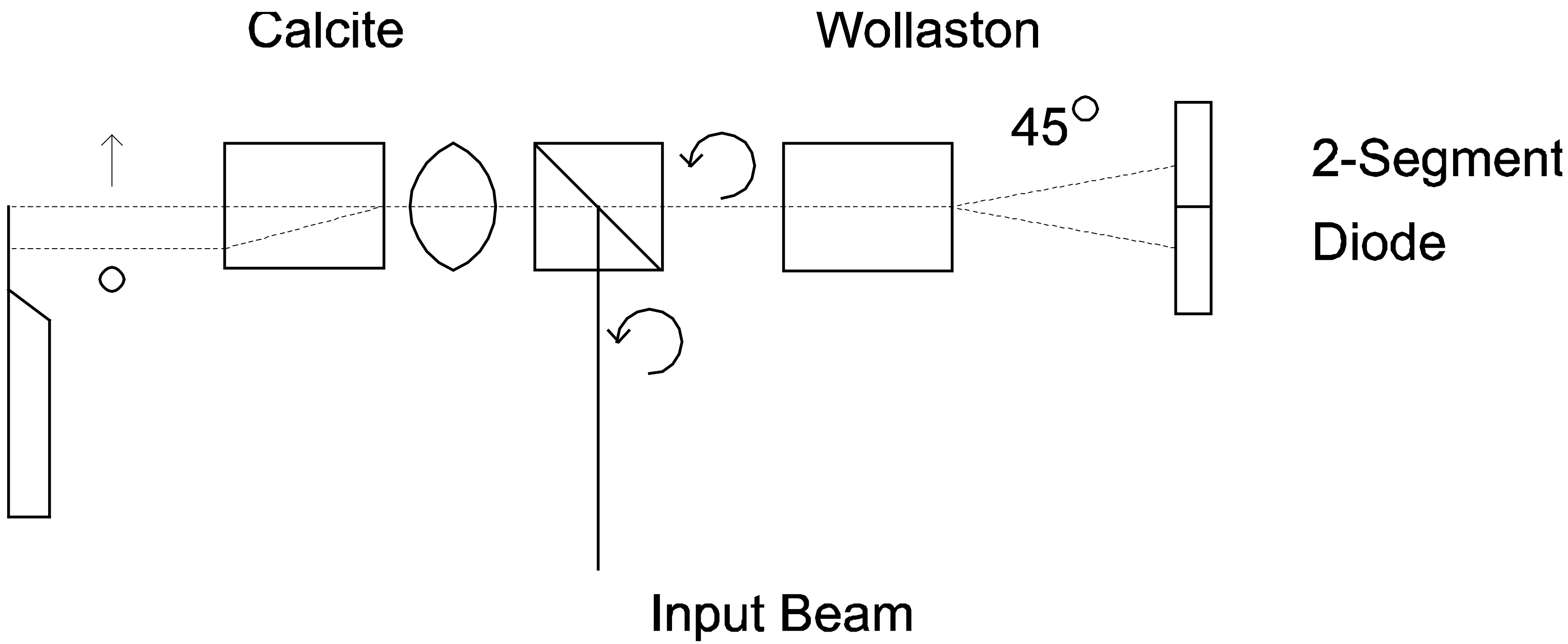
Interferometer AFM



Fiberoptic Interferometer

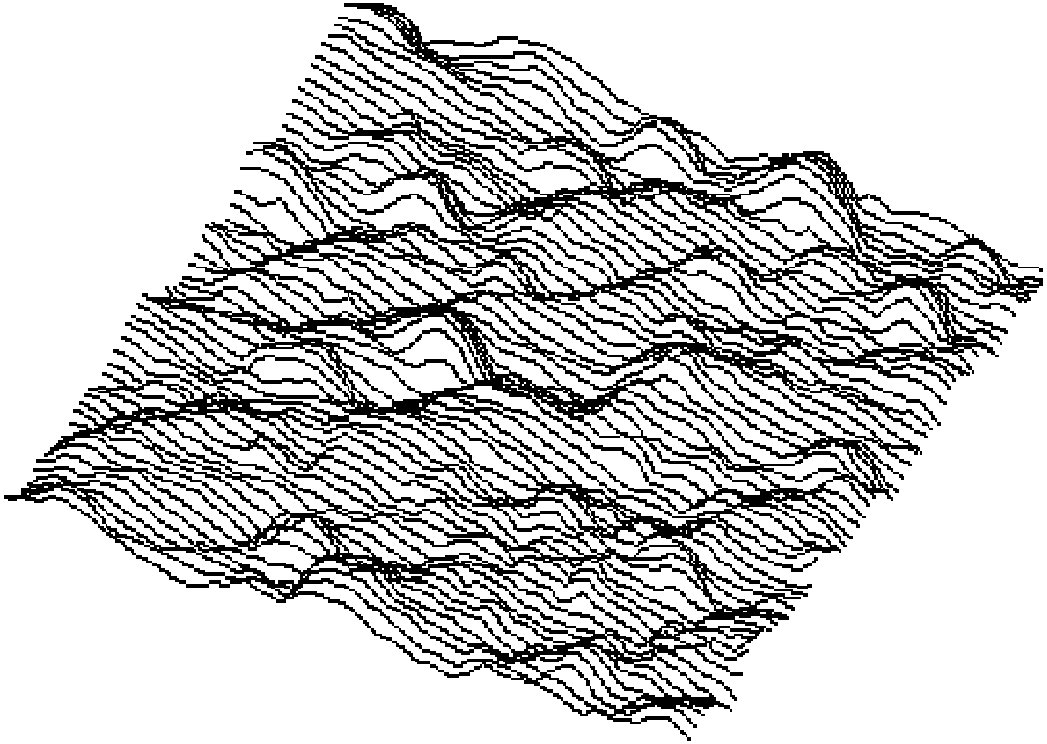


Nomarsky-Interferometer



Bildern kann man nicht immer trauen

Displaying Data: Lines

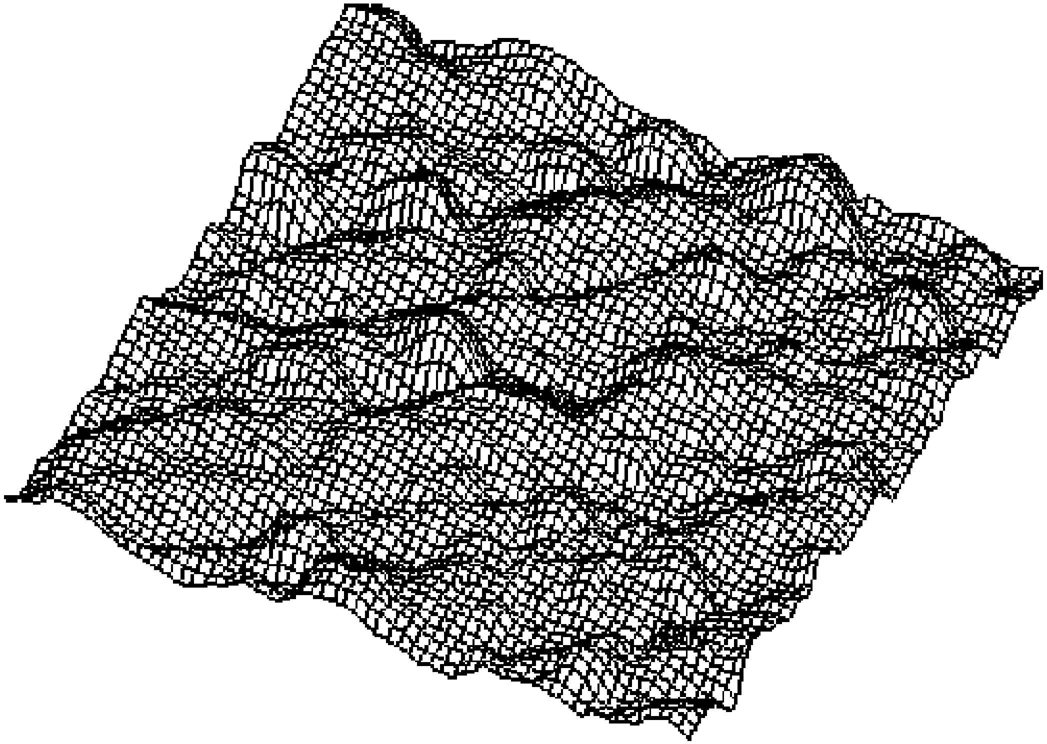


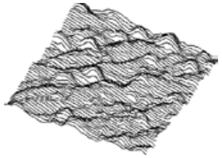
Lines

The profiles of the scan lines are shown one behind the other

Hidden lines may be removed

Displaying Data: Meshes





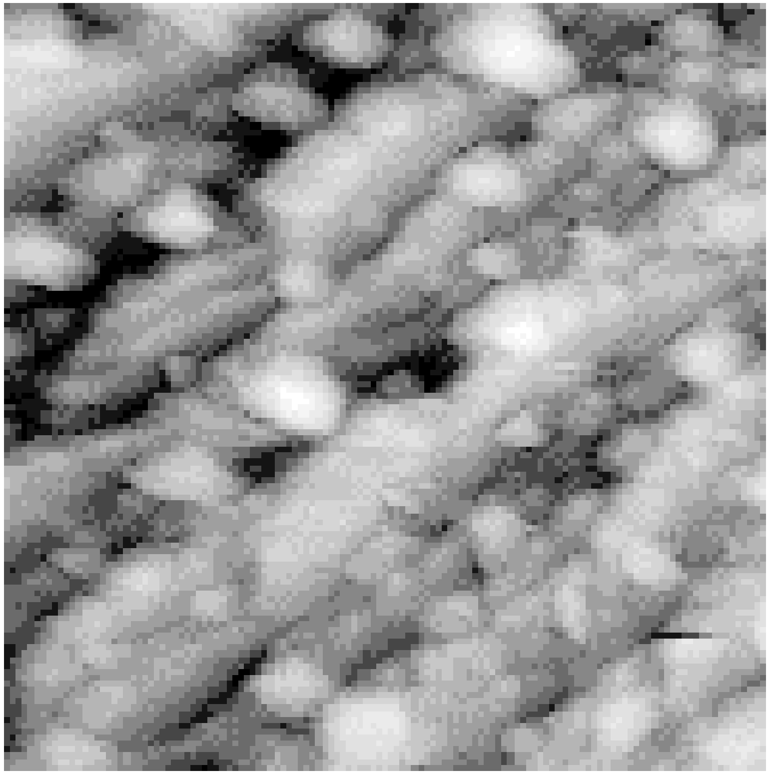
Lines

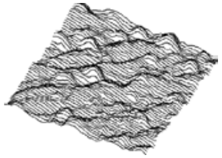
Meshes

The profiles of the scan lines are shown one behind the other. Some Data points are joined scan lines between

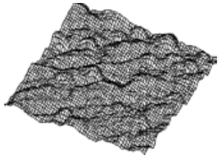
Hidden lines may be removed

Displaying Data: Topography





Lines

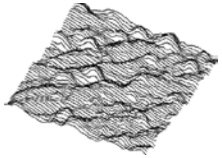


Meshes

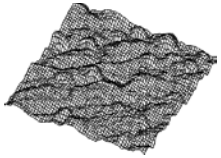
Topography

Every pixel shows its height as a value of gray. Usually light gray is up and dark gray is down

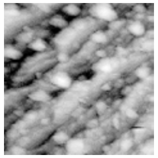
Displaying Data: Shading



Lines



Meshes

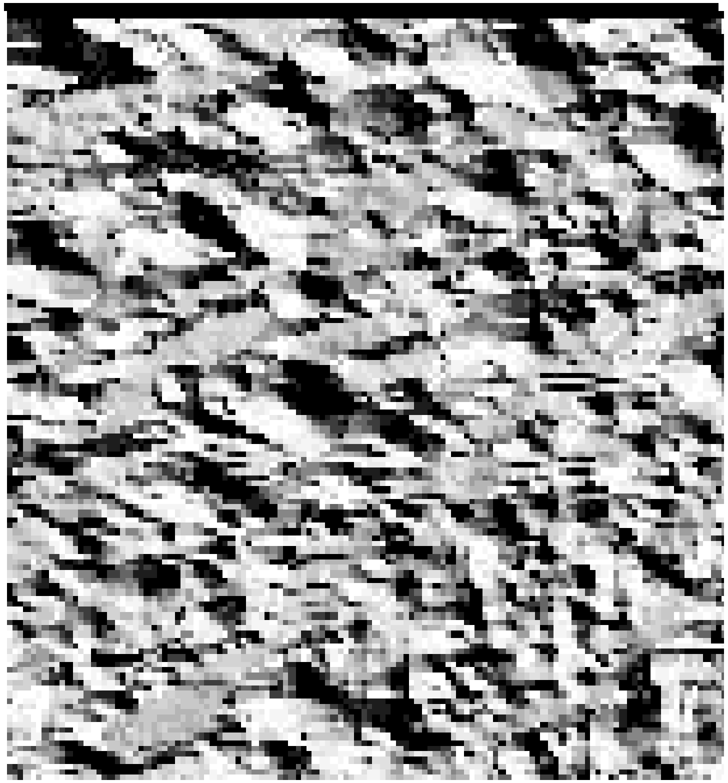


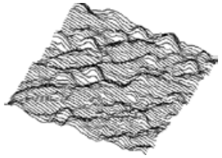
Topography

Shading

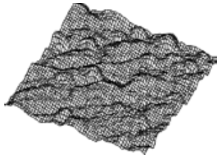
The shades of gray represent the directional gradient

Displaying Data: Shading

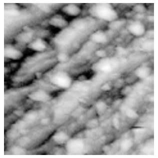




Lines



Meshes



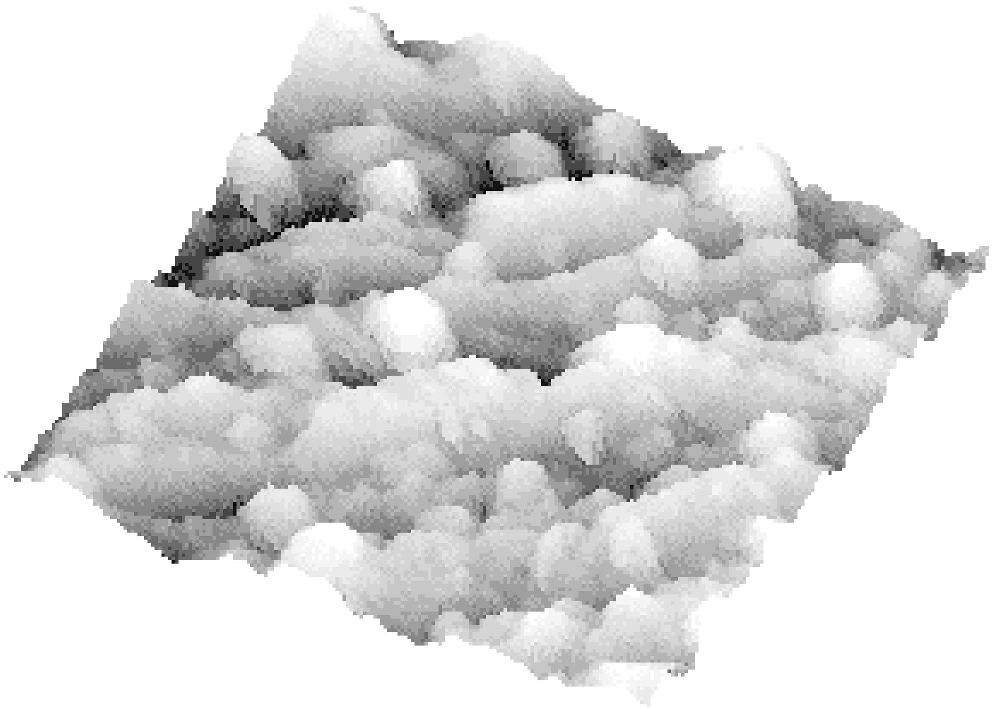
Topography

Shading

The shades of
gray represent the
directional gradient.

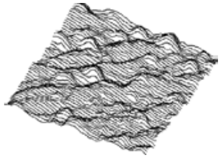
Some directions
hide features

Displaying Data: 3D-View

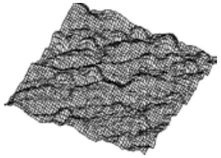


3D-View

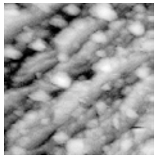
Every pixel shows its height as a value of gray. The gray scale is moved onto the mesh of the data.



Lines



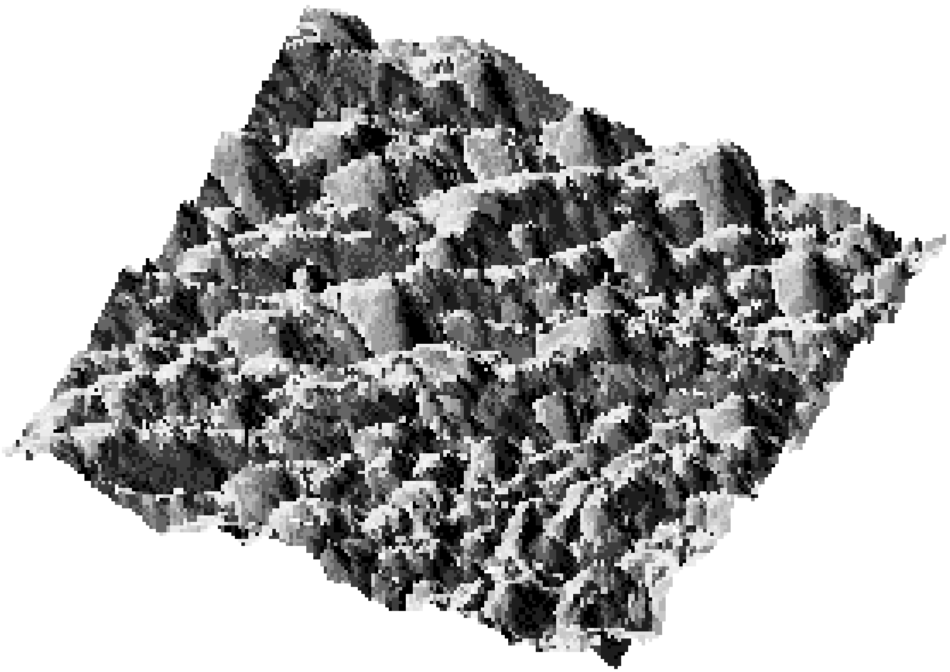
Meshes



Topography

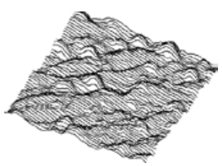
Shading

Displaying Data: 3D-View wth shading

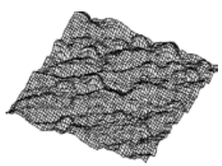


3D-View with shading

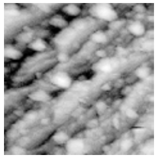
Every pixel shows its height as a shade of gray. The shade represents the directional surface gradient.



Lines



Meshes

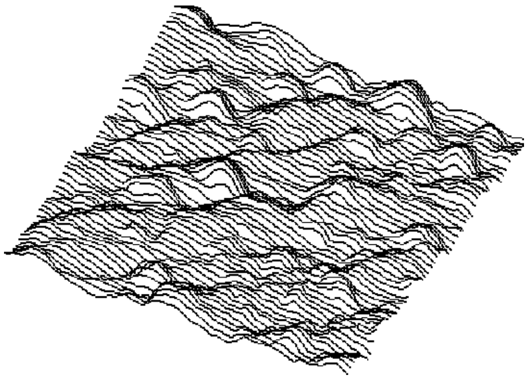


Topography

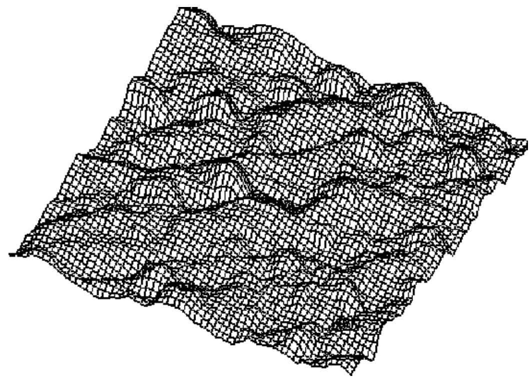
Shading

Daten darstellen

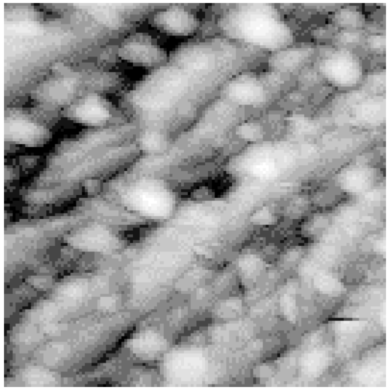
Mit der Datendarstellung kann man Daten verschleiern!



Lines

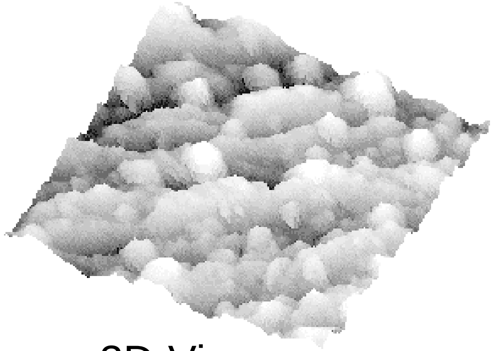


Meshes



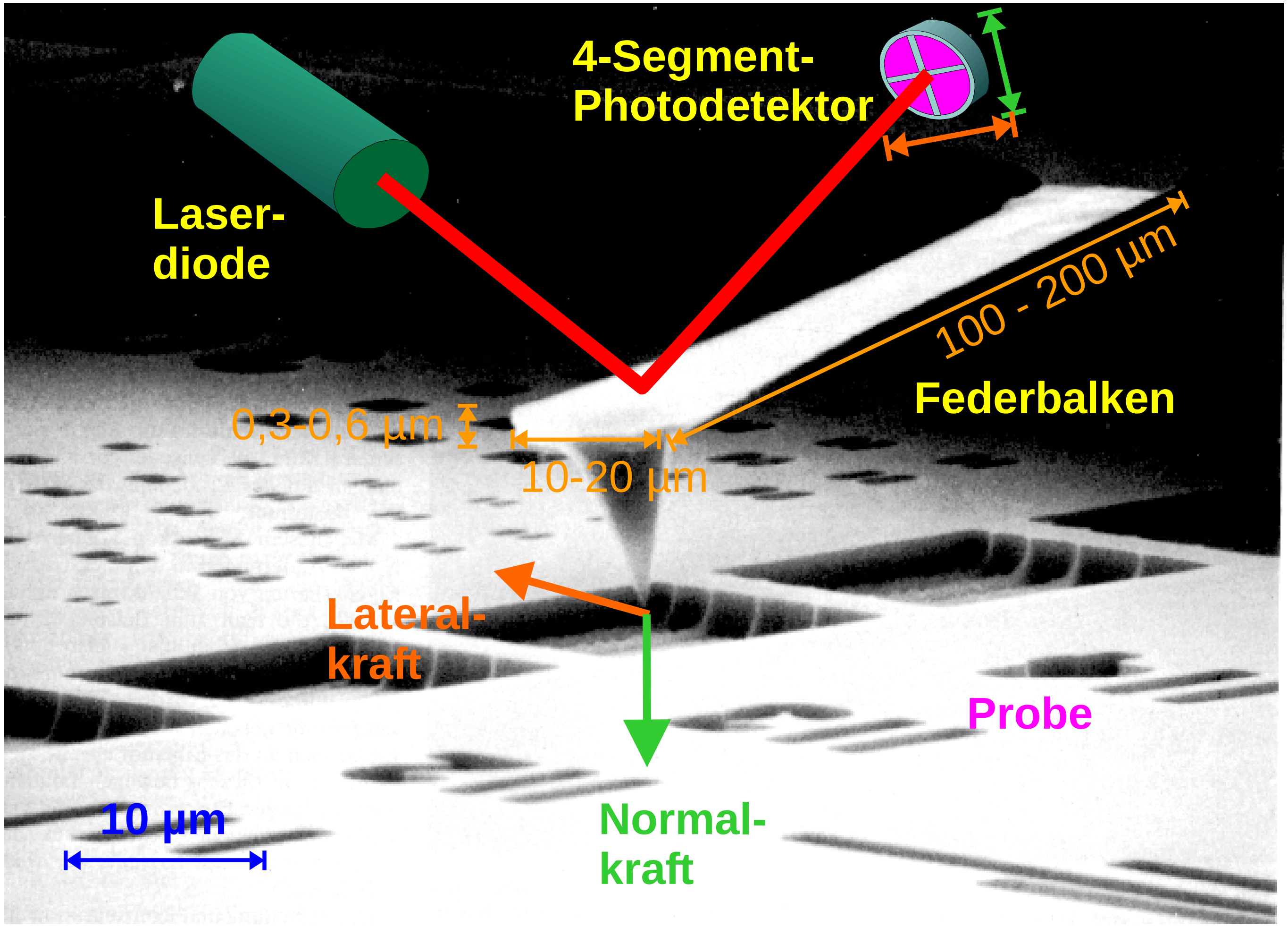
Topography

Shading

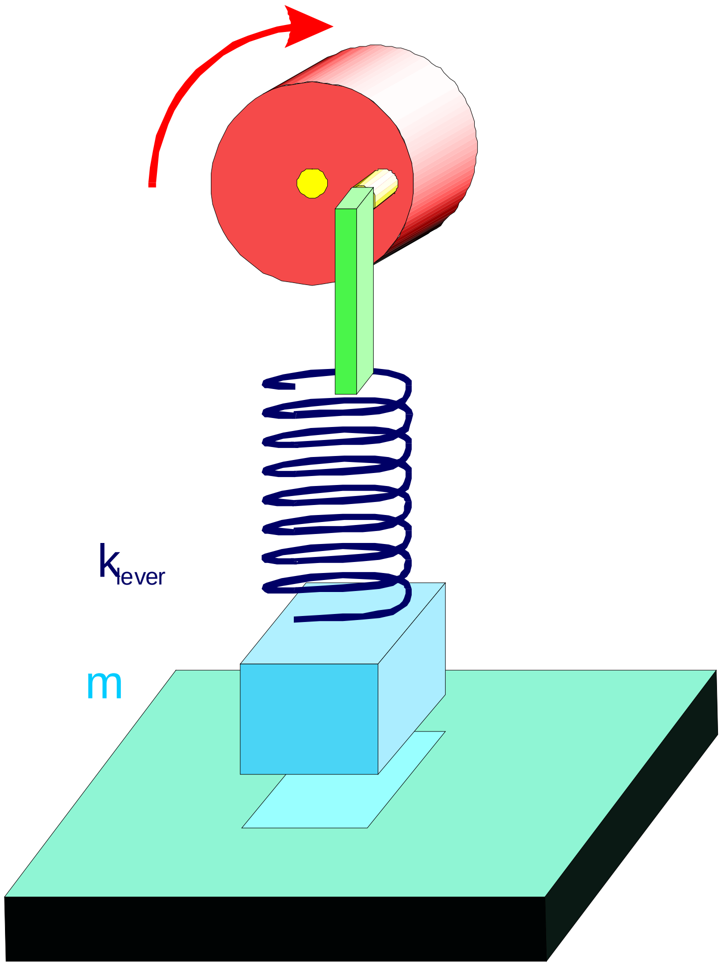


3D-View

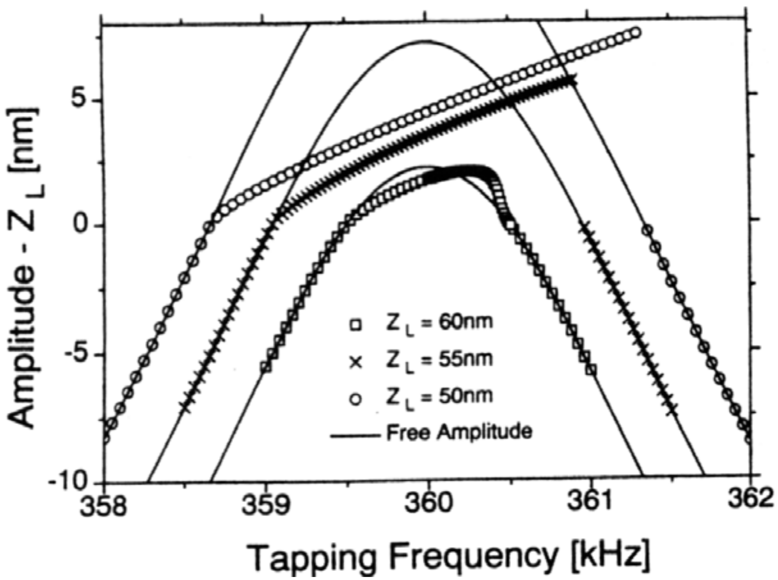
Prinzip Lichtzeiger SFM



Forces in Tapping Mode



Tip-sample interactions increases effective stiffness



Phase contrast at fixed excitation frequency ω

Oscillator equation

$$\ddot{x}(t)+\frac{\omega_0}{Q}\dot{x}(t)+\omega_0^{\,2}x(t)=\frac{x_0}{k}\cos(\omega t)$$

Amplitude at fixed ω

$$x(\omega)=\frac{x_0}{\sqrt{\left\{1-\left(\frac{\omega}{\omega_0}\right)^2\right\}^2+\left(\frac{\omega}{Q\omega_0}\right)^2}}$$

Phase at fixed ω

$$\tan(\alpha(\omega))=\frac{1}{Q}\frac{\omega\cdot\omega_0}{\omega_0^2-\omega^2}$$

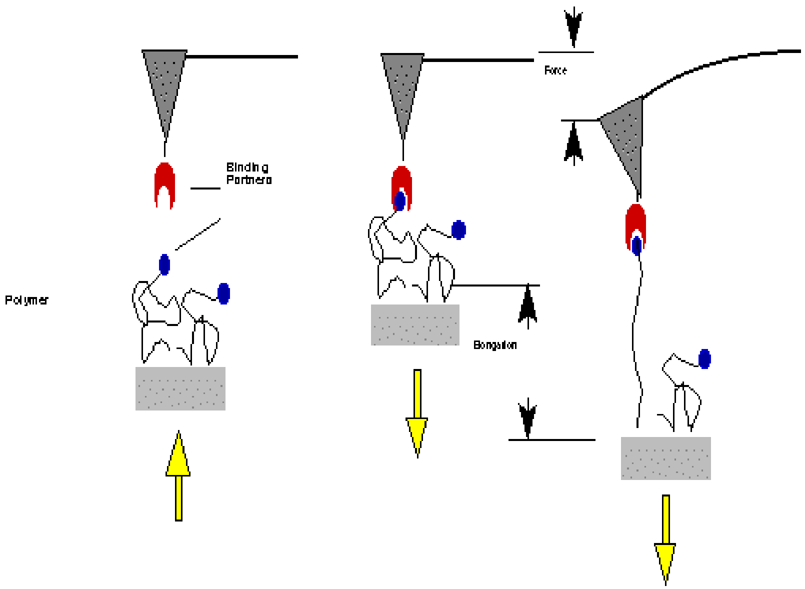
Energy loss per cycle

$$\frac{\Delta E}{E}\cong\frac{2\pi}{Q}$$

Phase-energy loss relation

$$\frac{\Delta E}{E}=2\pi\frac{\omega_0^2-\omega^2}{\omega\cdot\omega_0}\tan(\alpha(\omega))$$

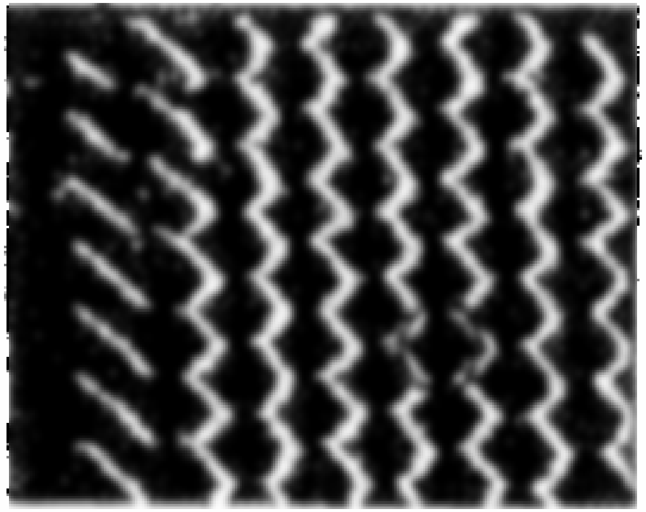
Rasterkraftmikroskope: Molekülmanipulation



Hermann Gaub, LMU München

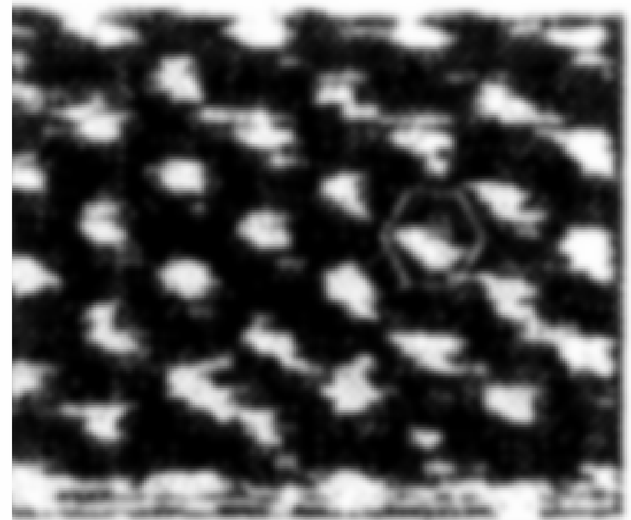
Atome

Graphit



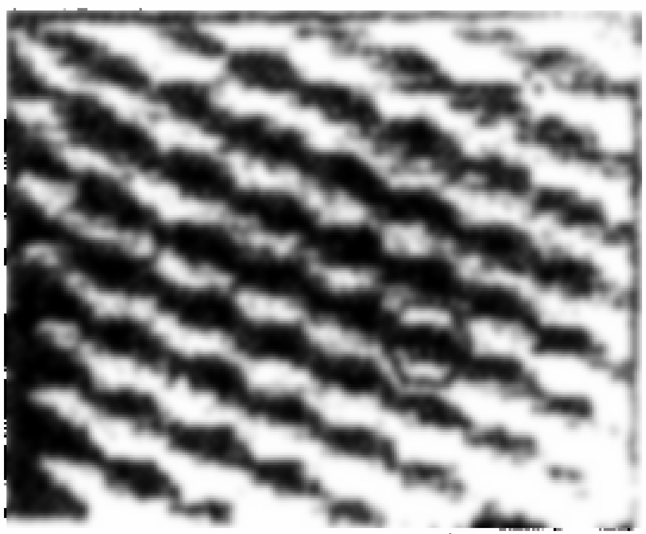
5 Å

(a) AFM



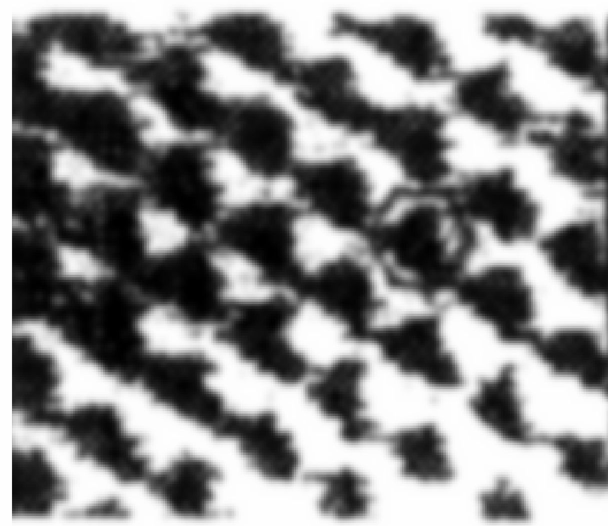
5 Å

(a) AFM



5 Å

(b) STM

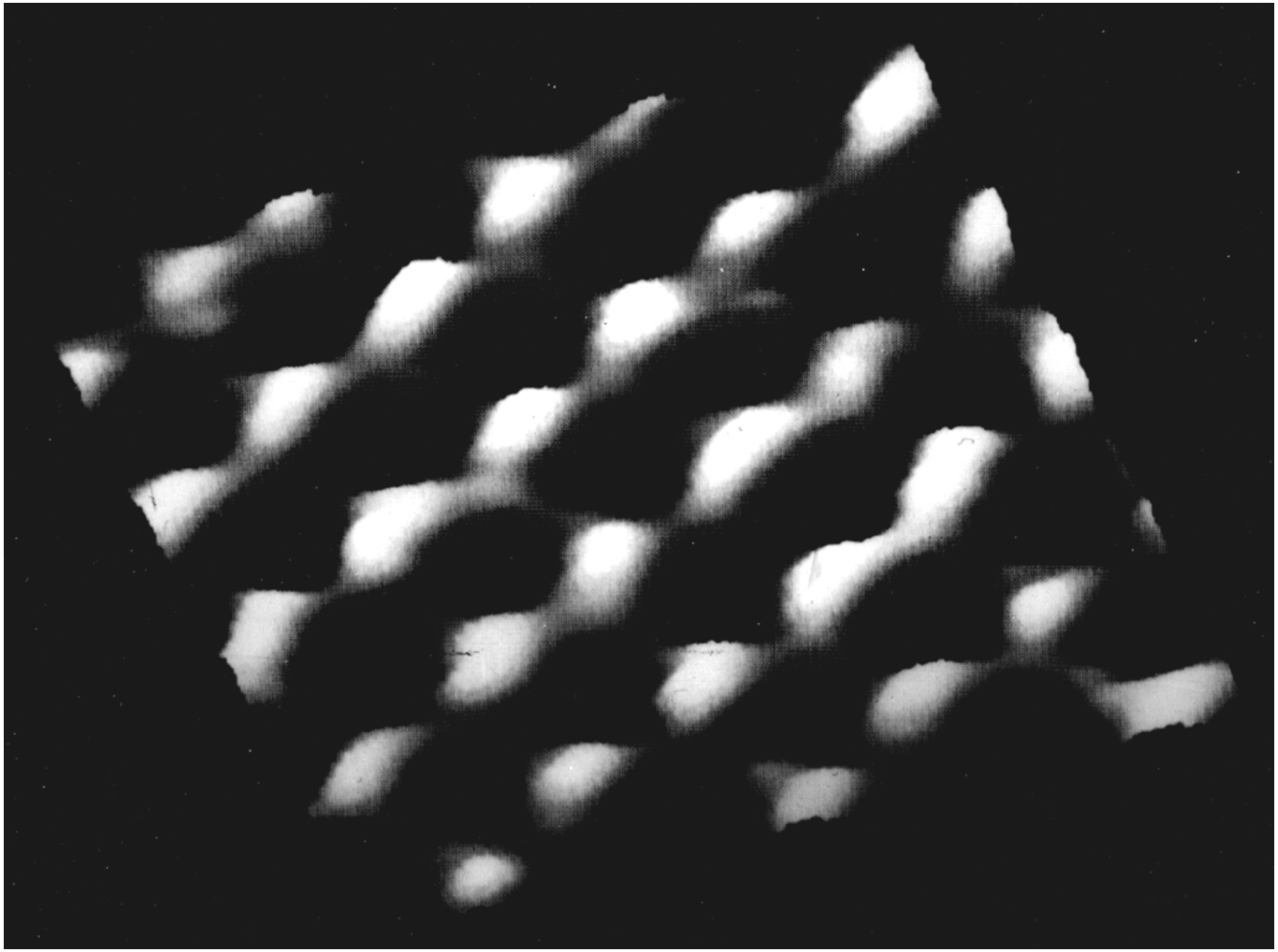


5 Å

(b) STM

Scanning force/tunneling microscopy of a graphite surface in air Y. Sugawara, T. Ishizaka, and S. Morita, J. Vac. Sci. Technol. B9 pp. 1092-1095 1991

Glimmer unter Wasser



B. Drake, O. Marti, P. Hansma, UCSB, 1987, 2,6 x 2,6 nm^2

Schimmel T, Koch T, Kuppers J, Lux-Steiner M. True **atomic resolution** under ambient conditions obtained by **atomic force microscopy** in the **contact** mode. [Journal Paper] *Applied Physics a (Materials Science Processing), vol.A68, no.4, April 1999*

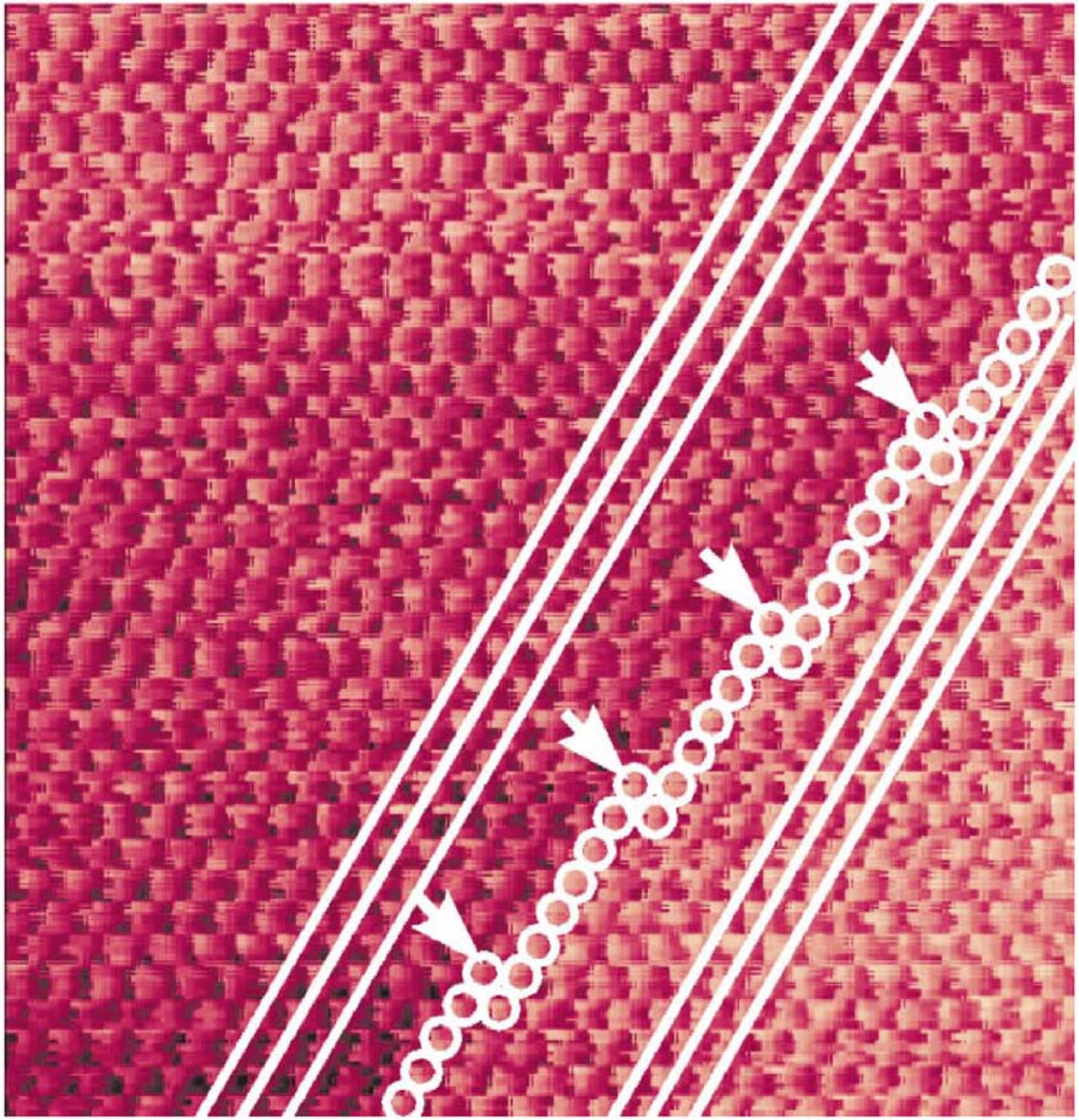
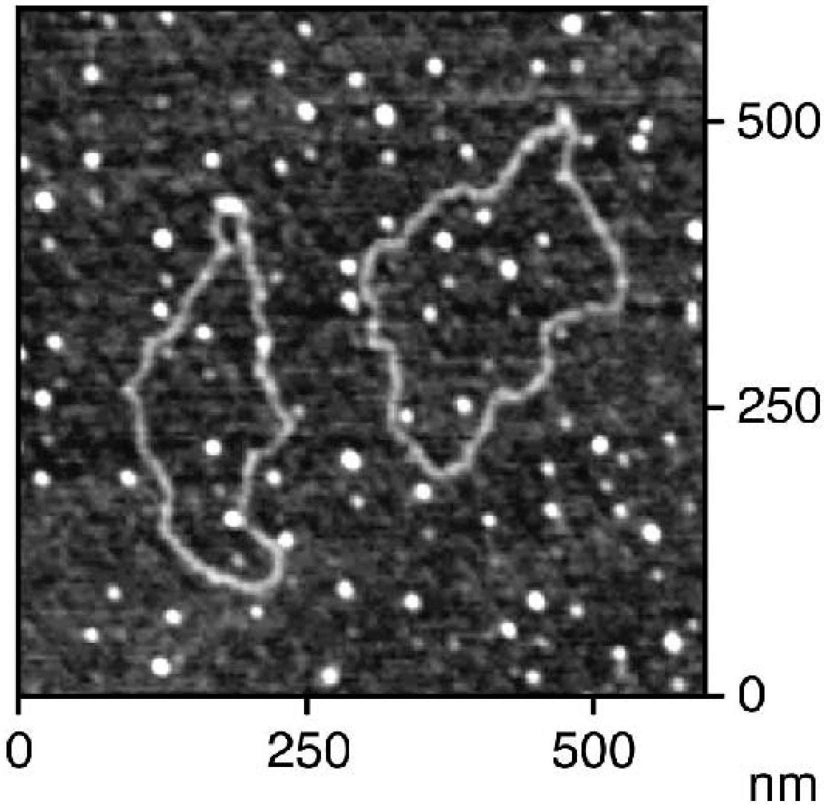


Fig. 3. AFM data of Fig. 2 together with some illustrations. The directions of the atomic rows on the upper and lower terrace are indicated by *white lines*, the atomic positions of the upper terrace right at the step edge are indicated by *white circles* and the four kink sites are labelled by *arrows*. The scanning direction in the image is from left to right

Moleküle

DNA Plasmids with polymeric tip

Soft, entirely photoplastic probes for scanning force microscopy. G. Genolet, J. Brugger, M. Despont, U. Drechsler, and P. Vettiger, N. F. de Rooij, D. Anselmetti REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 70, NUMBER 5 MAY 1999



AFM image (0.6x0.6 μm^2) of DNA–plasmid (pGEM-3Zf vector from Promega Corporation, Madison, WI). The width of the DNA strand is 5–6 nm. The z scale was color adjusted to 1.5 nm.

Carbon Nanotubes

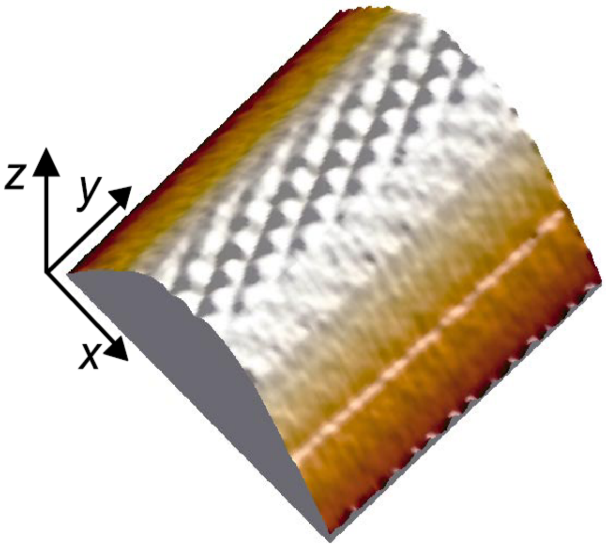


FIG. 1 (color). A three-dimensional view of the atomically-resolved carbon nanotube image acquired under constant frequency shift feedback control in the noncontact regime; $\Delta f = -65.3$ Hz, $A = 2.4$ nm, image size 3 nm $\times$ 3 nm. The atomic-scale features are clearly observed around the elevated topmost area and are still slightly observed on the sloping sides. The maximum corrugation amplitude is about 40 pm.

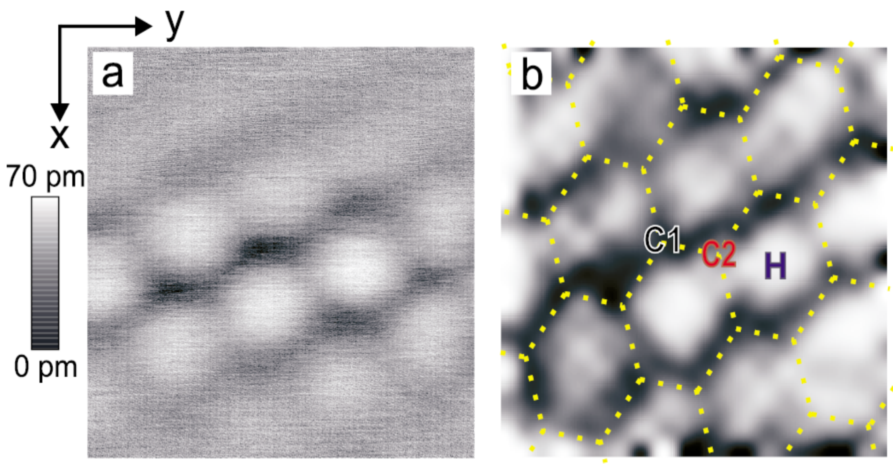


FIG. 2 (color). (a) Constant frequency shift image with atomic-scale features; $\Delta f = -69.6$ Hz, $A = 2.3$ nm, image size 1 nm $\times$ 1 nm. For better visualization of the atomic-scale features, a parabolic curvature has been subtracted from the raw data. (b) Contour plot of the z values recorded at the stabilizing points during capturing the 3D-FFS. Note that the 20×20 data points have been extrapolated to 400×400 image points for better visualization. The individual $\Delta f(z)$ curves acquired at the positions labeled C1, C2, and H are shown in Fig. 3. The slightly distorted corresponding carbon lattice is depicted on the image.

Ashino M, Schwarz A, Behnke T, Wiesendanger R. **Atomic-resolution** dynamic **force microscopy** and spectroscopy of a single-walled carbon nanotube: characterization of inter**atomic** van der Waals **force**s. [Journal Paper] *Physical Review Letters, vol.93, no.13, 24 Sept. 2004, pp.136101/1-4.*

Entnetzung

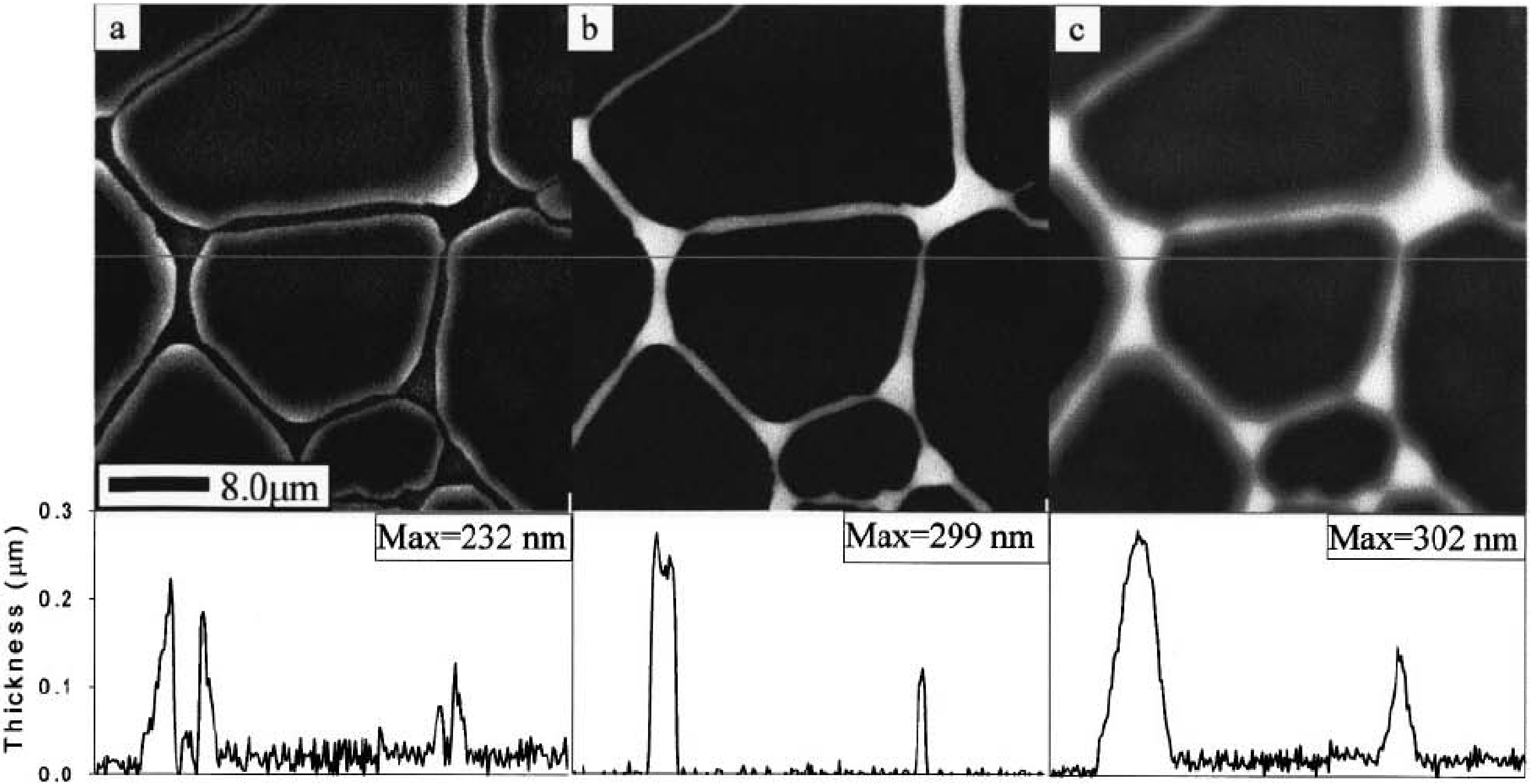
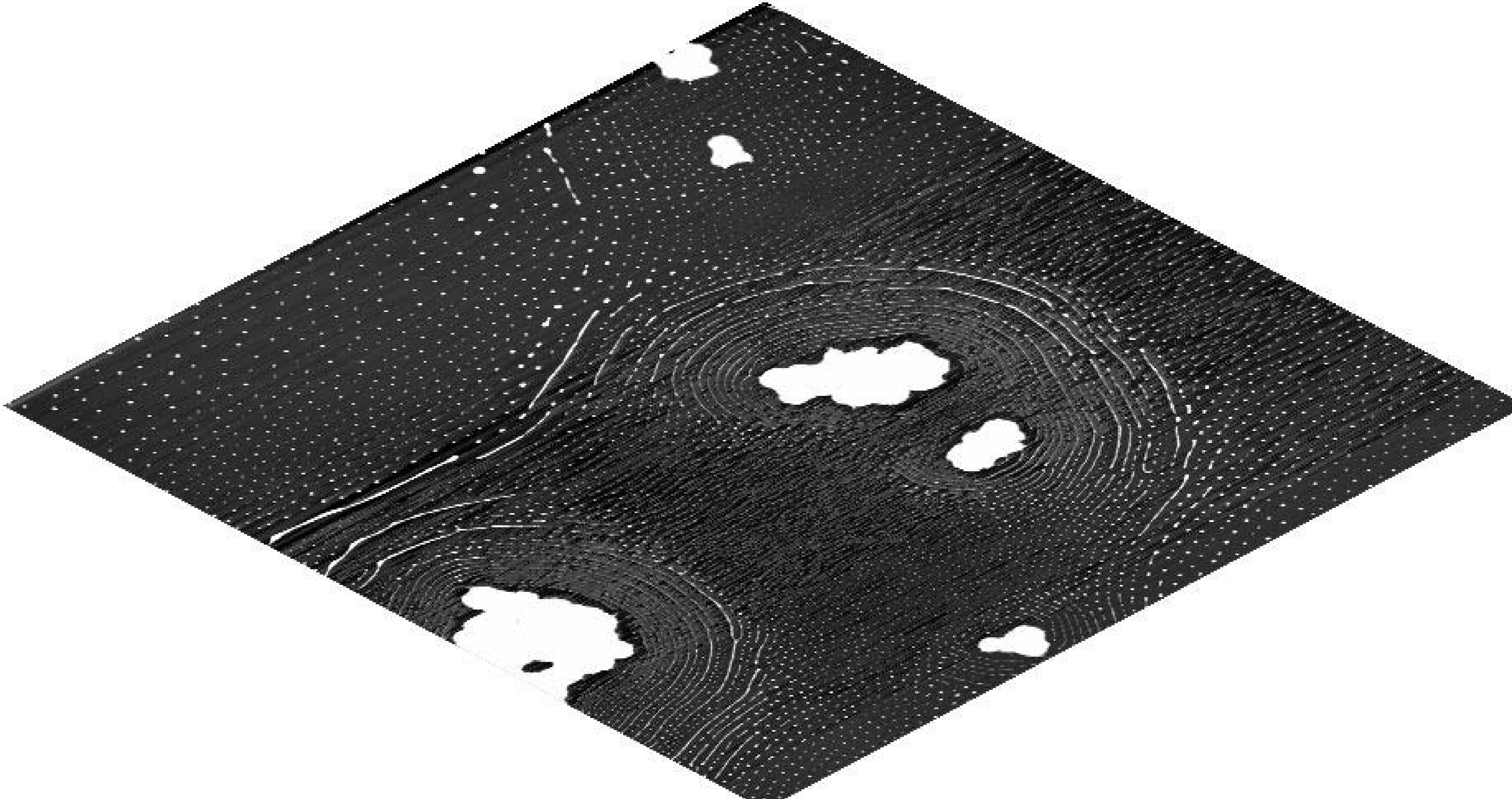
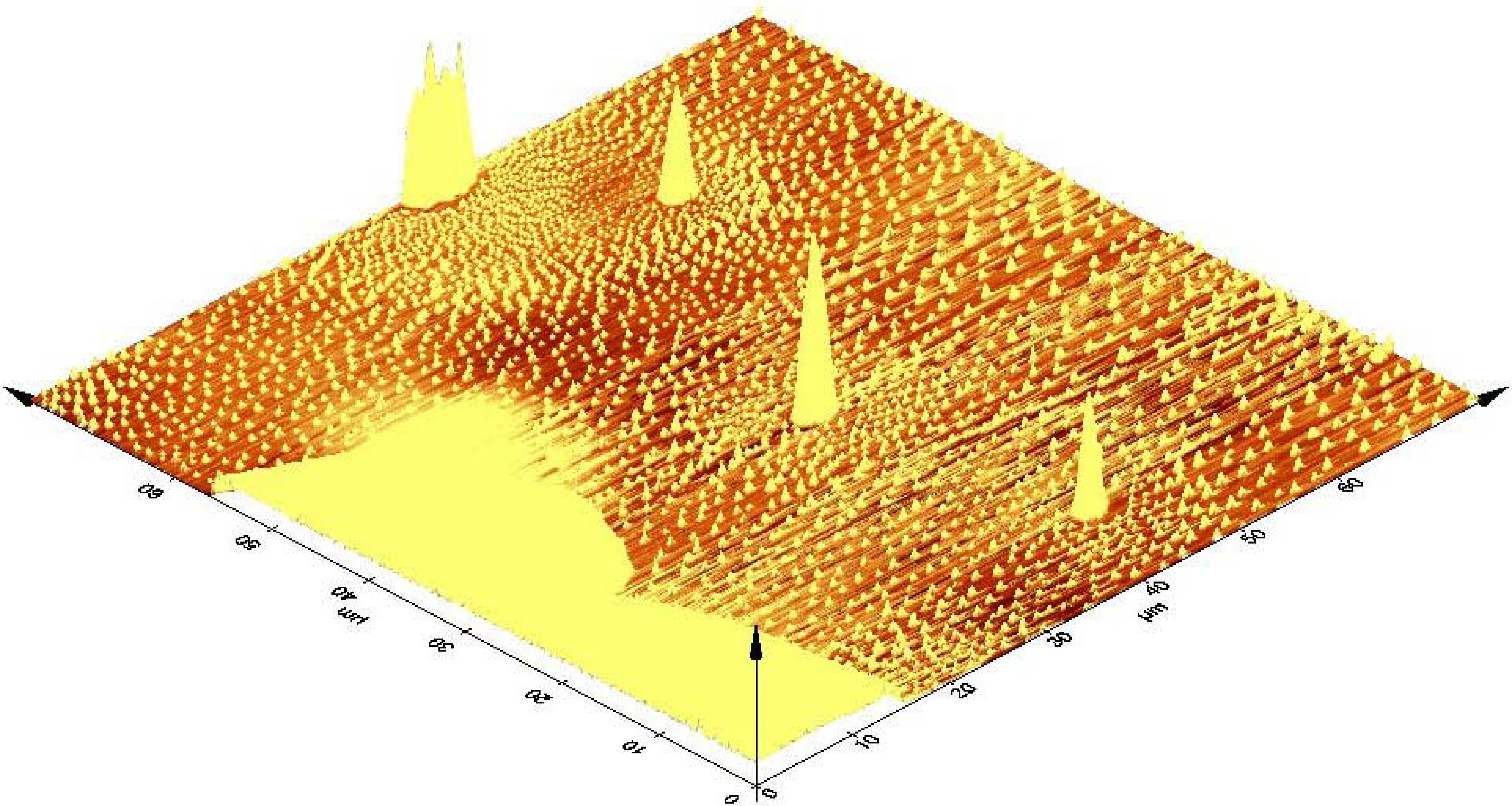


FIG. 2. Thickness maps of PBrS/PS bilayer after annealing for 1 week: (a) PS map, (b) PBrS map, and (c) total thickness.

Ade H, Winesett DA, Smith AP, Anders S, Stammler T, Heske C, Slep D, Rafailovich MH, Sokolov J, Stohr J. Bulk and surface characterization of a **dewetting** thin film polymer bilayer. [Journal Paper] *Applied Physics Letters, vol.73, no.25, 21 Dec. 1998, pp.3775-7.*

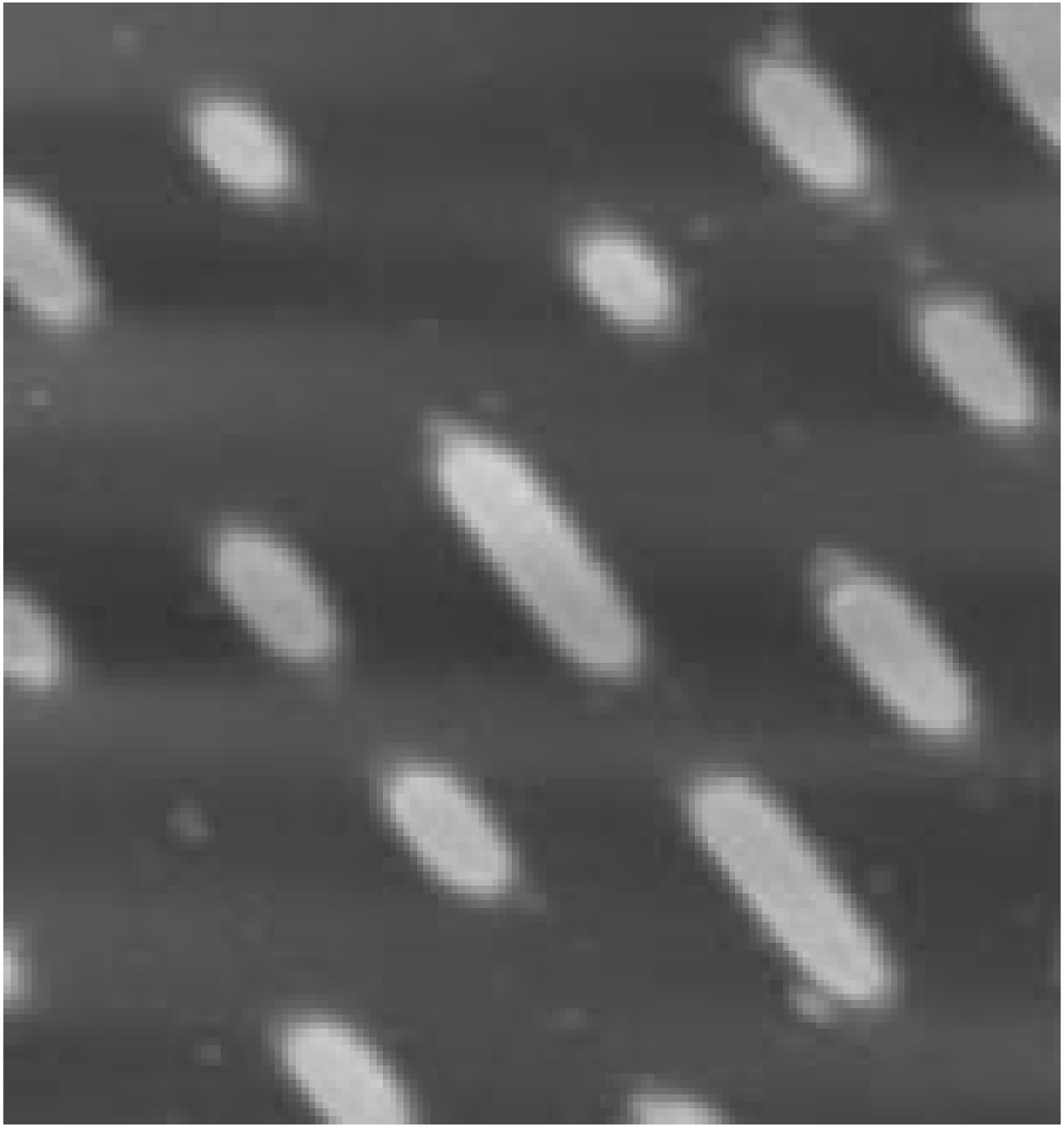




0
10
20
30
µm
40
50
60
0
10
20
30
µm
40
50
60

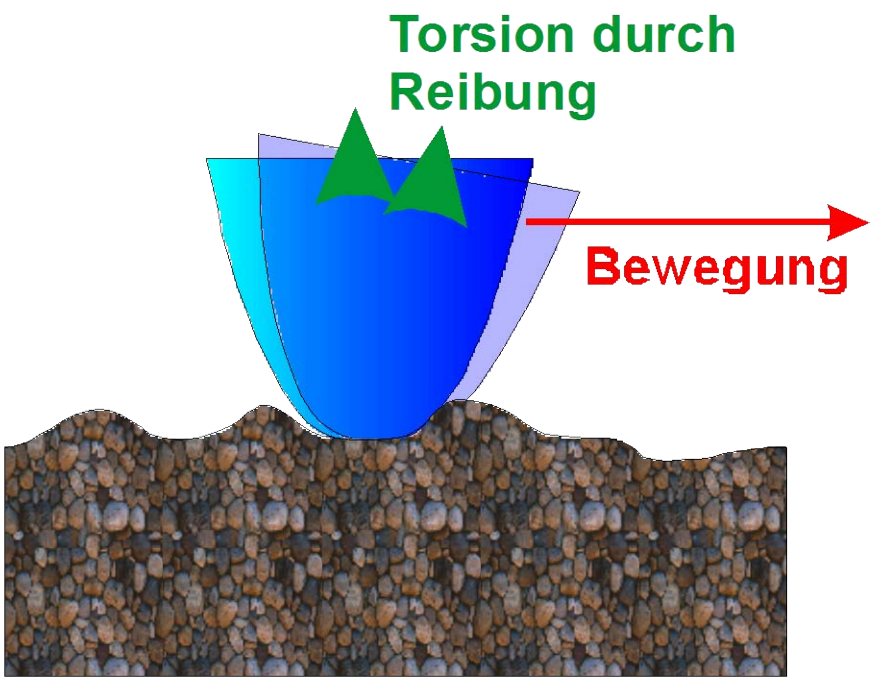
C D

http://invsee.asu.edu/srinivas/pdf/AFM_of_Compact_Disc.pdf



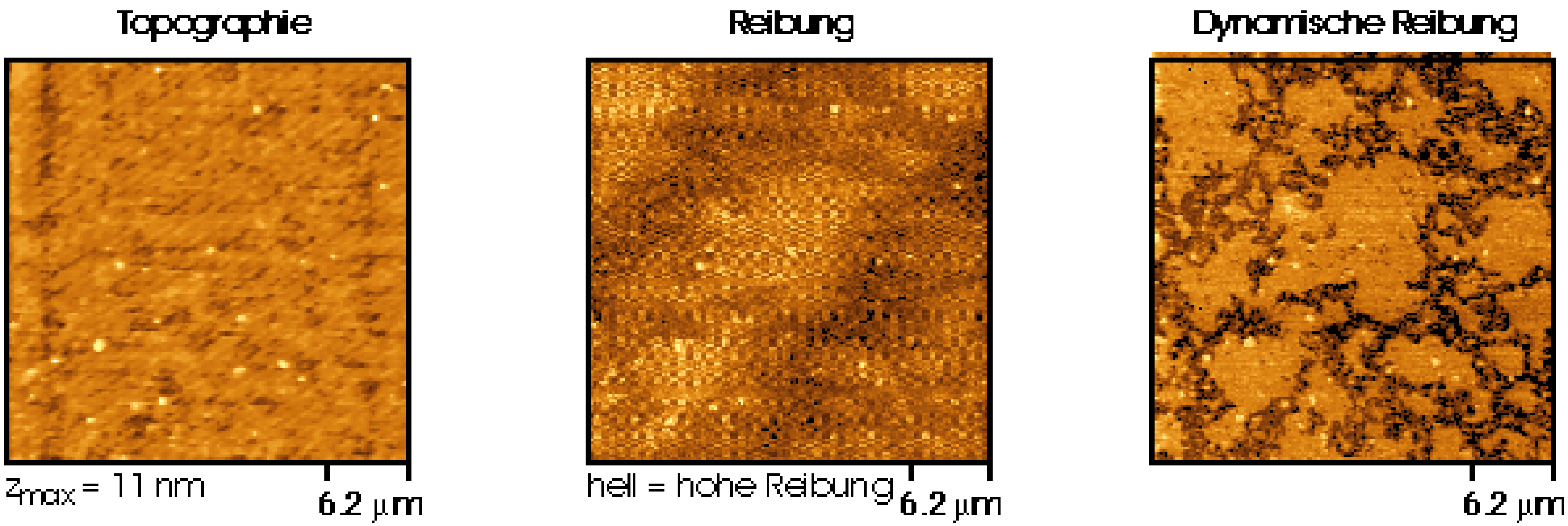
Reibung

Reibungsmessungen



- Die Tastspitze reibt an der Probenoberfläche
- Die Materialpaarungen bestimmen den Reibungskoeffizienten
- Auflösung: Nanometer
- Nanotribologie

Reibungsmessungen



Einzelne Polyethylenmoleküle auf Glimmer

Dynamischer Reibungskontrast kann kleinste organische Verunreinigungen auf nichtorganischen Oberflächen detektieren

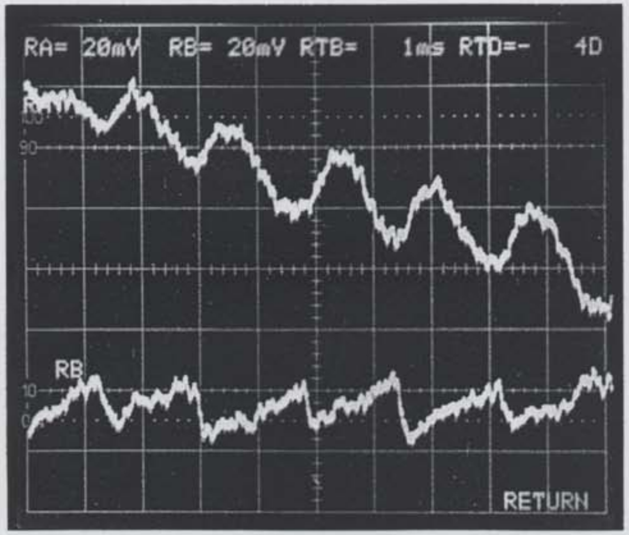
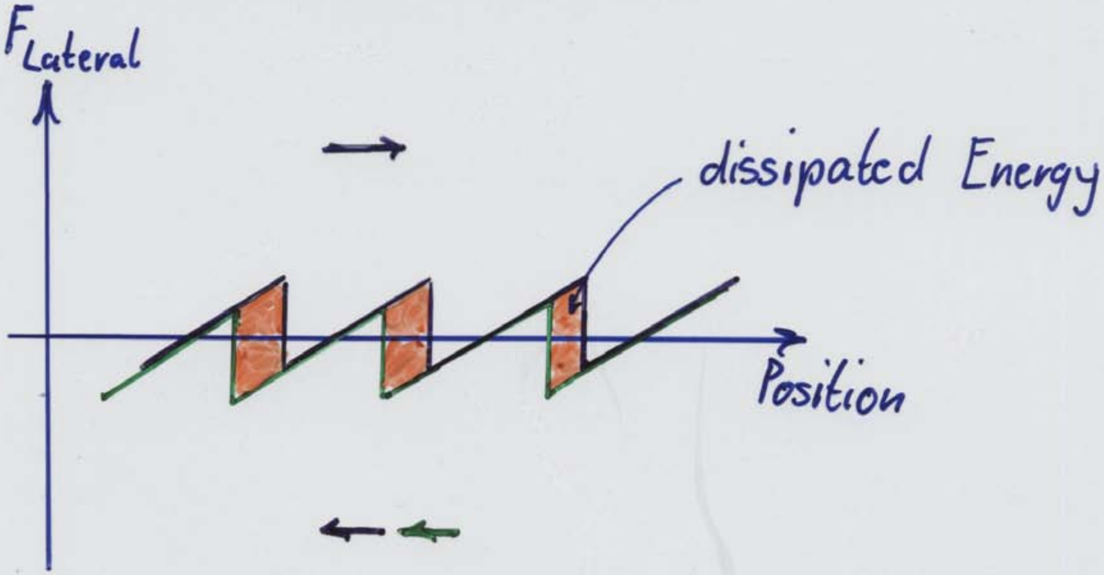
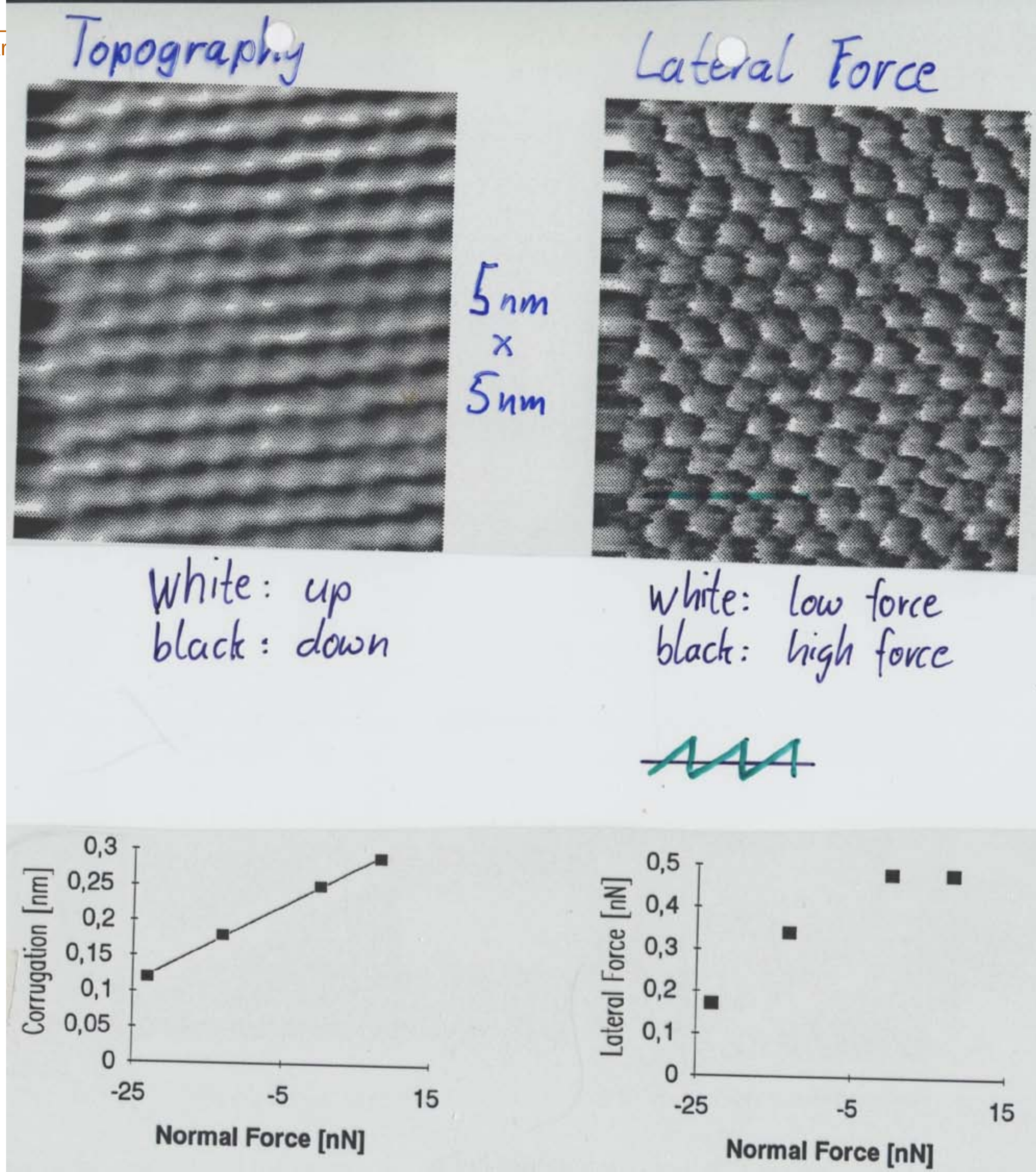


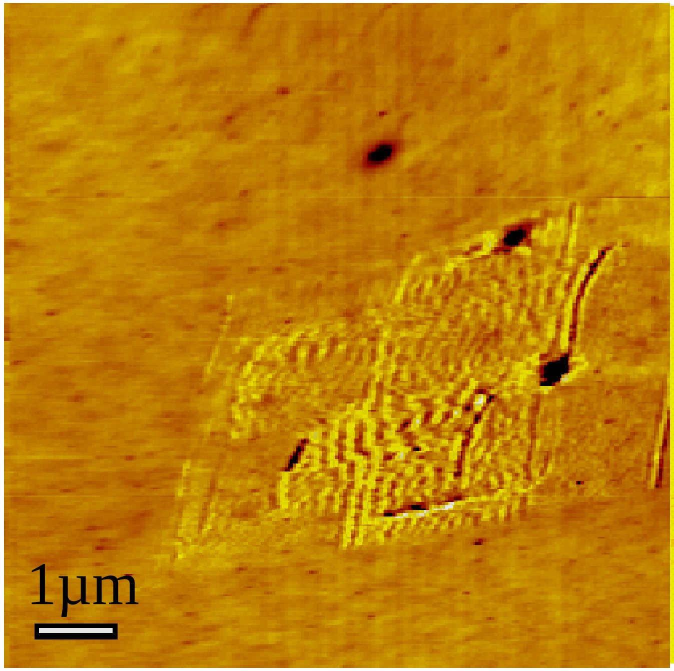
Figure 3. Photograph of the oscilloscope traces of the topography $z(x)$ (upper trace) and the frictional force F_F (lower trace). The traces were recorded simultaneously. The scale for topography is 0.15 nm/division and for



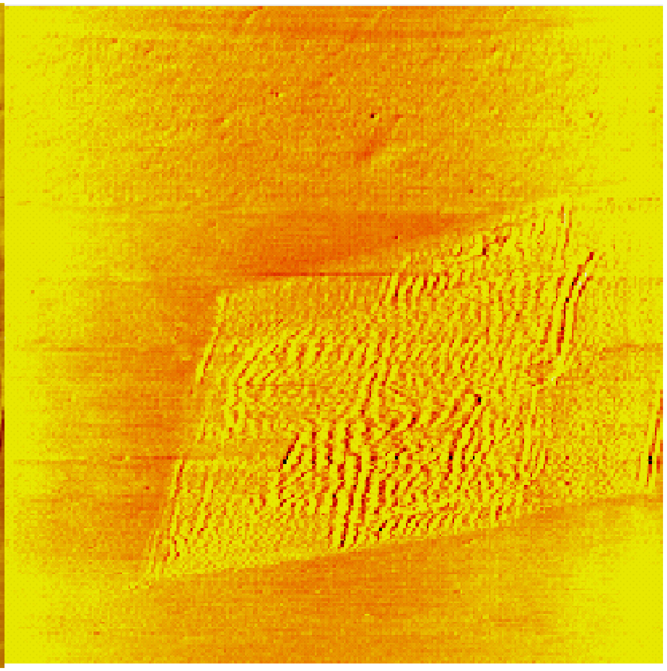
⇒ Conservative Forces dominate


Topography
Lateral Force
5nm x 5nm
white: up
black: down
white: low force
black: high force
Corrugation [nm]
0,3
0,25
0,2
0,15
0,1
0,05
0
-25
-5
15
Normal Force [nN]
Lateral Force [nN]
0,5
0,4
0,3
0,2
0,1
0
-25
-5
15
Normal Force [nN]

Influence of Lateral Forces

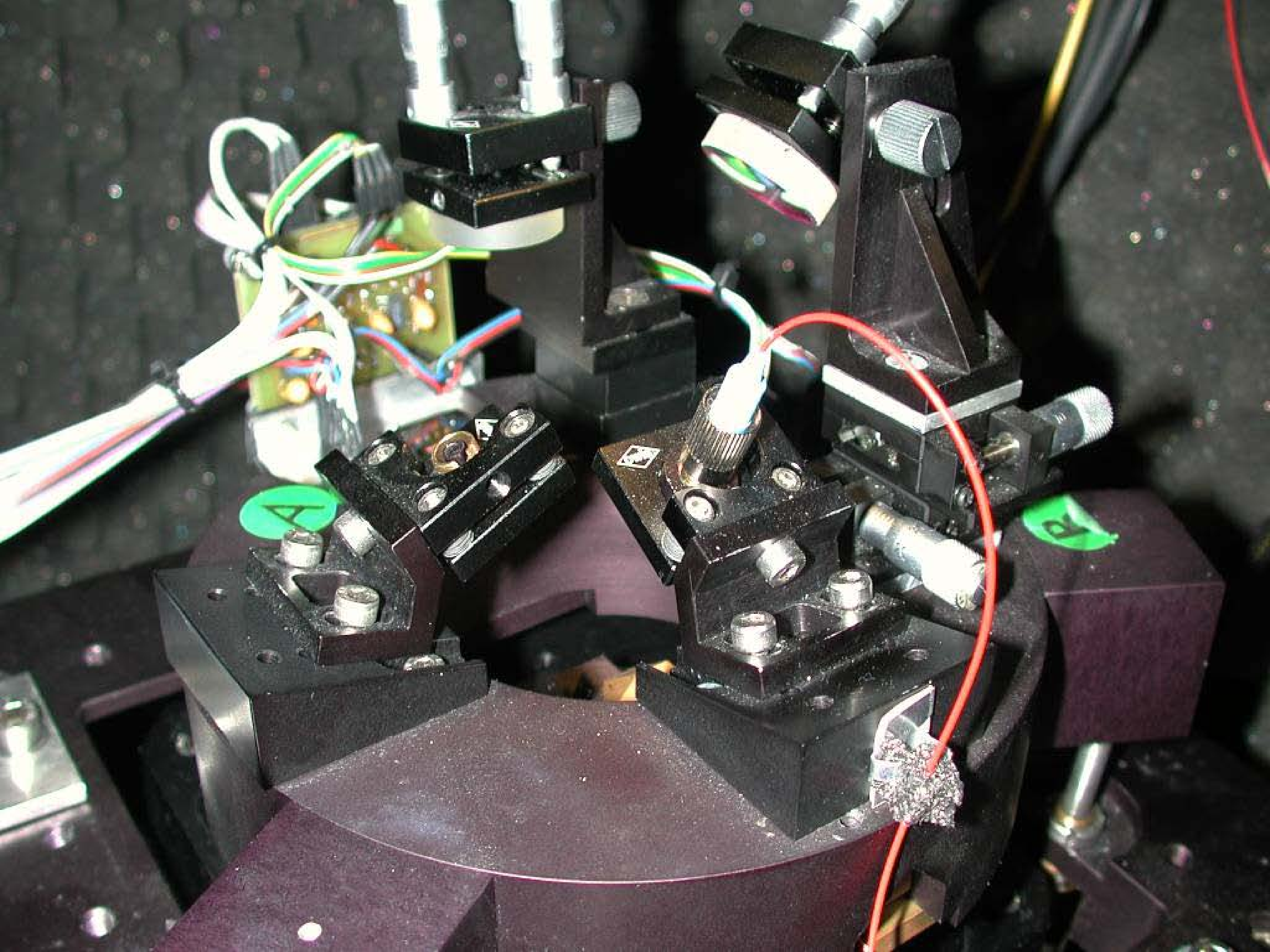


Topography

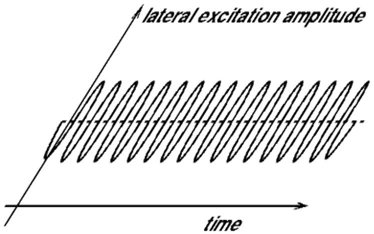


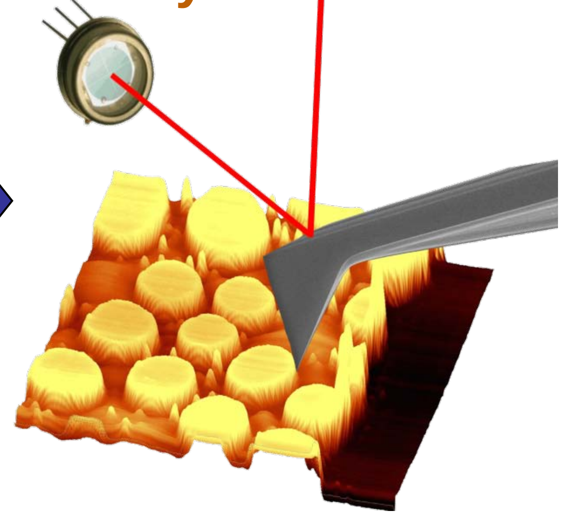
Friction

Sample: PMMA, annealed
T=80°C
Height scale: 13nm

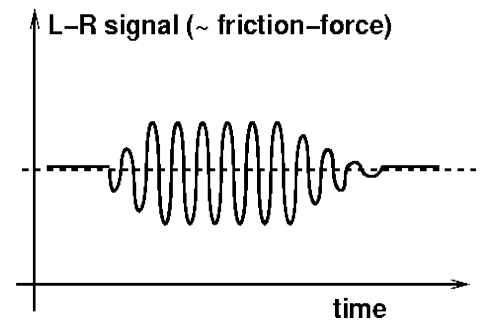

A
R

Our Measurement System for Lateral Forces



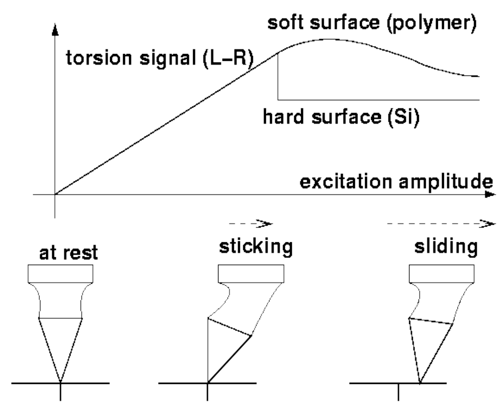


data directly processed by high-speed lock-in amplifier improving signal-detection at low s/n-ratios



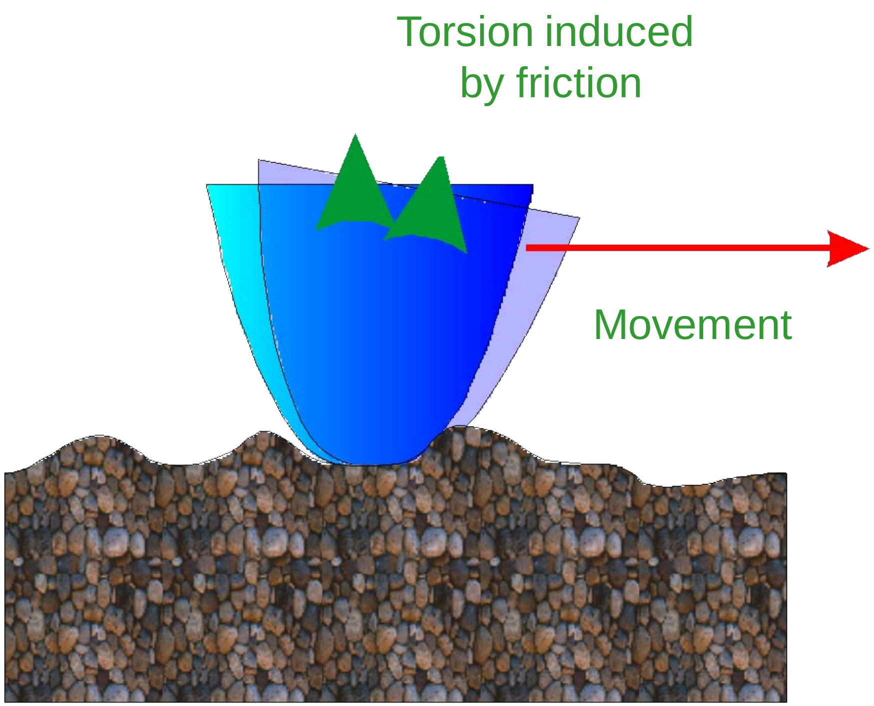
1. **calibration using a defined torque at sloped surface**
2. **direct conversion to friction coefficient relative to Si**
3. **correlation with PFM data possible**

explanation



torque by lateral motion relative to the sample causes L-R signal during contact

Measurements of Lateral Forces



- AFM probe tip is in contact with sample surface
- Friction coefficient given by material combination
- Resolution: nm
- Nanotribology

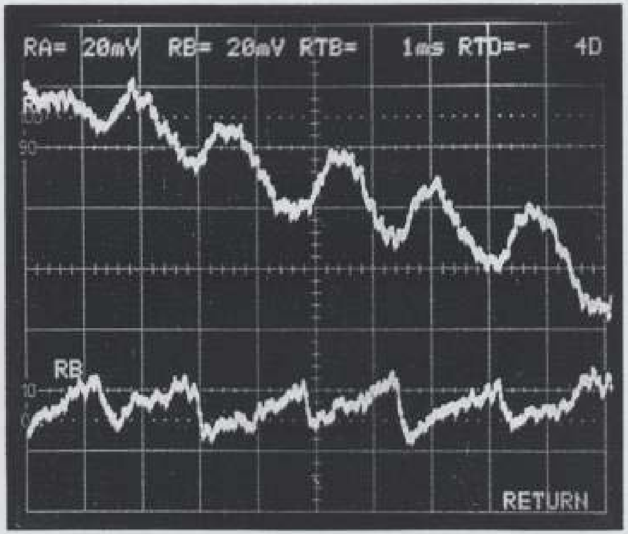
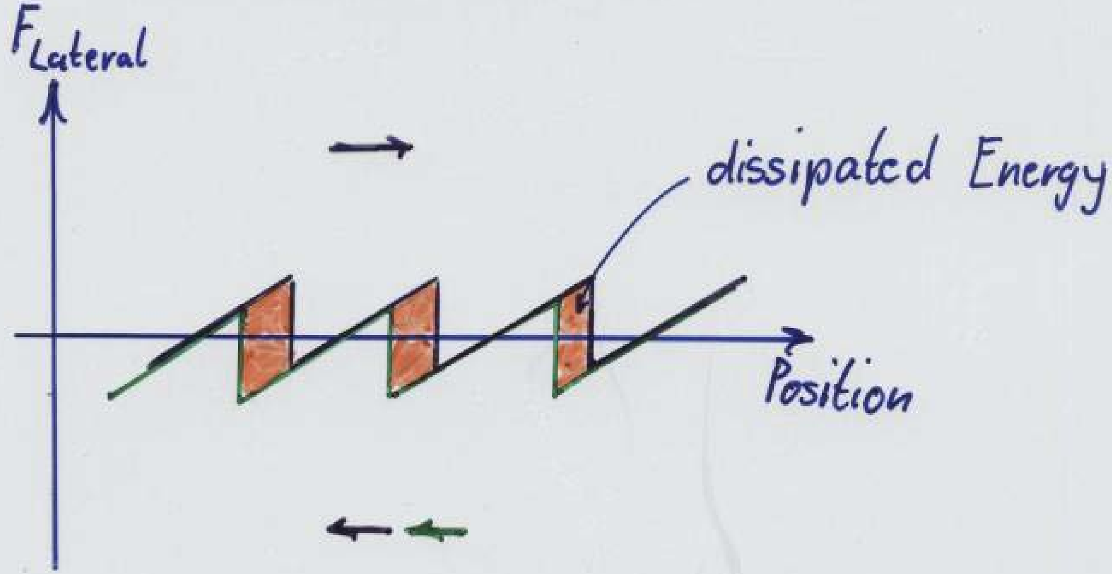


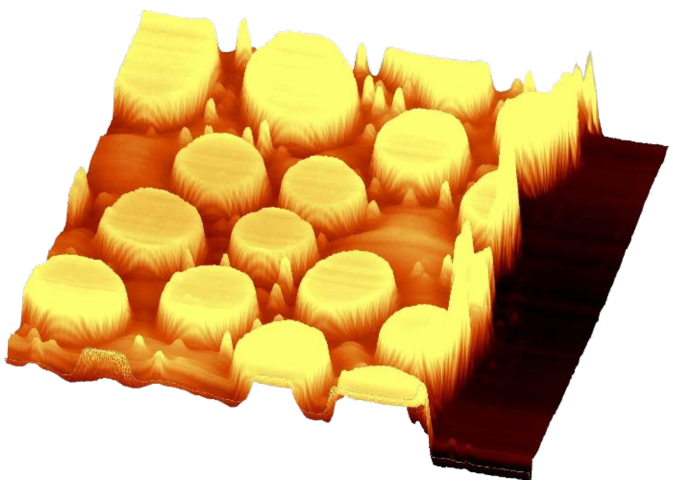
Figure 3. Photograph of the oscilloscope traces of the topography $z(x)$ (upper trace) and the frictional force F_F (lower trace). The traces were recorded simultaneously. The scale for topography is 0.15 nm/division and for



⇒ Conservative Forces dominate

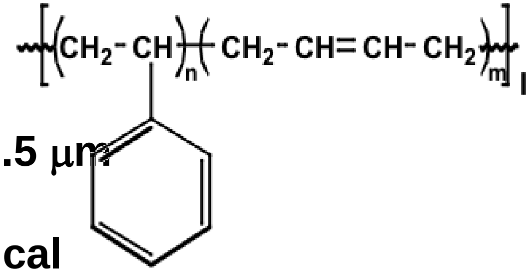
Samples for Our Setup

Dewetting Polymers



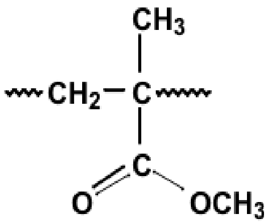
courtesy of S. Hild

SBR:



- R_g = 14 nm
- straight chain-length = 3.5 µm
- M = 390.000 g/mol
- 30% S - 70% BR, statistical
- non-crosslinked

PMMA:



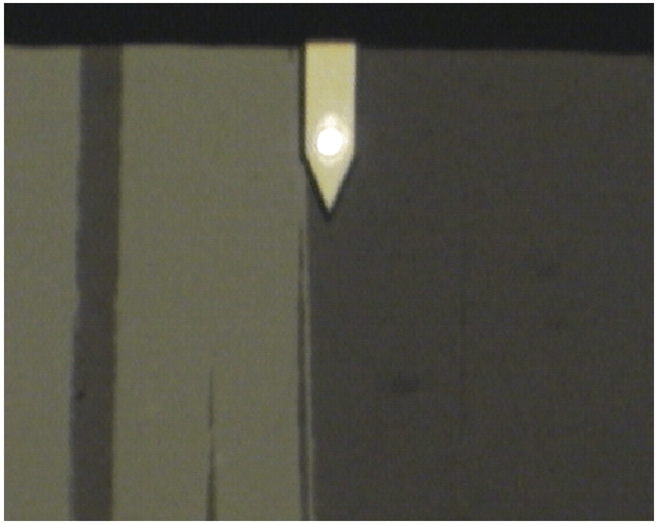
- R_g = 7 nm
- straight chain-length = 309 nm
- M = 100.000 g/mol

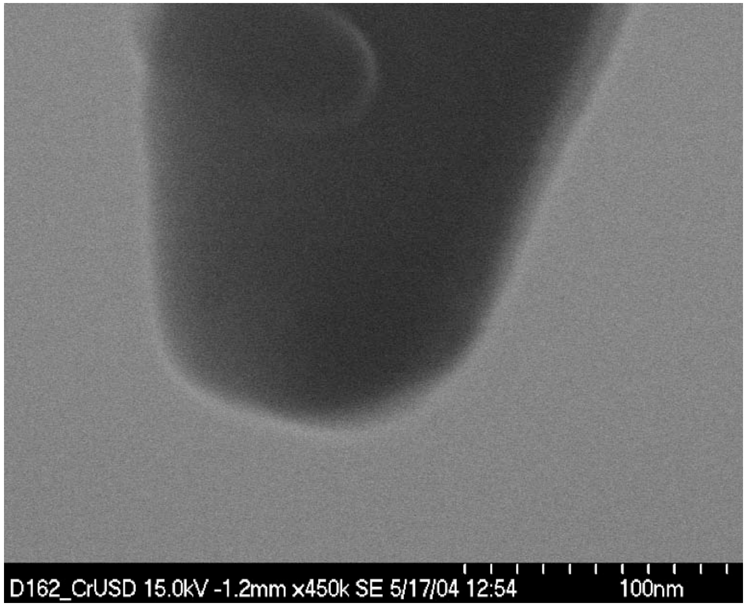
Silicon: hard crystal; no visco-elasticity (lit.: 60-150 GPa)
PMMA: elastic & hard (lit.: 3.3 GPa)
SBR: rubber-elastic; pronounced relaxation phenomena
lit.: 50-150 MPa (bulk; static)

The Strategy

protocol for our measurements:

- ✓ fresh scratch for every measurement
- ✓ at a given F_{max} = 1.2 μN
- ✓ scanning 15x15 μm^2 @ 3 s/line @ 300x300 px
- ✓ PFM 1 kHz @ 245 nm amplitude
  (calibrated by a Vibrometer - SIOS, Ilmenau)

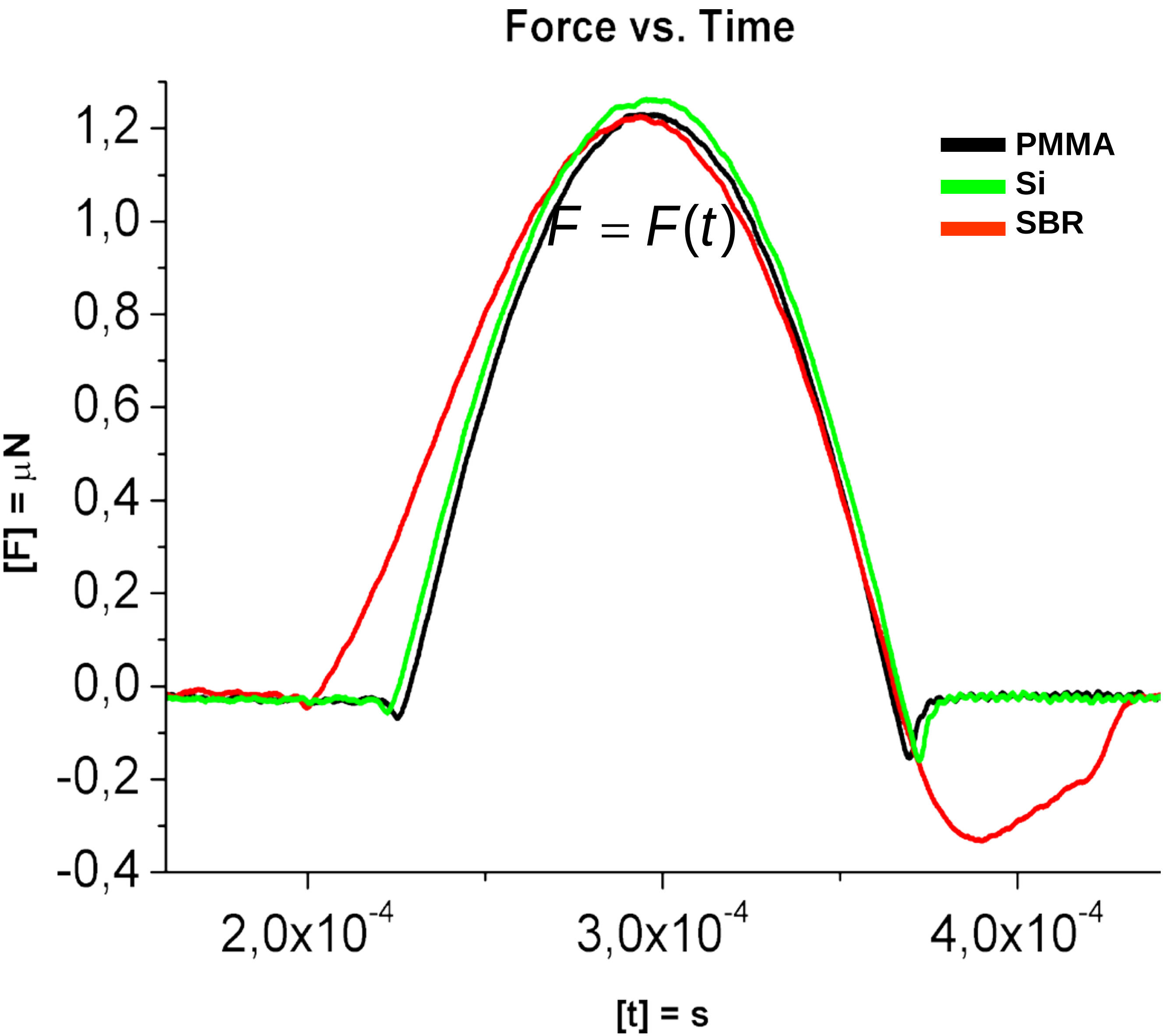




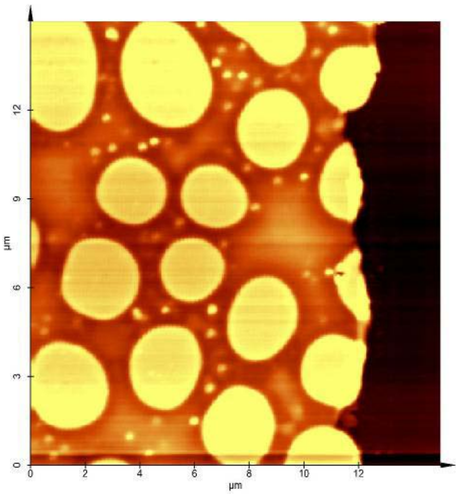
tips in use:

- 42 N/m @ 300 kHz ("HF-levers")
- 50-100 nm radius justified
- spherical apex
- constant radius when broken

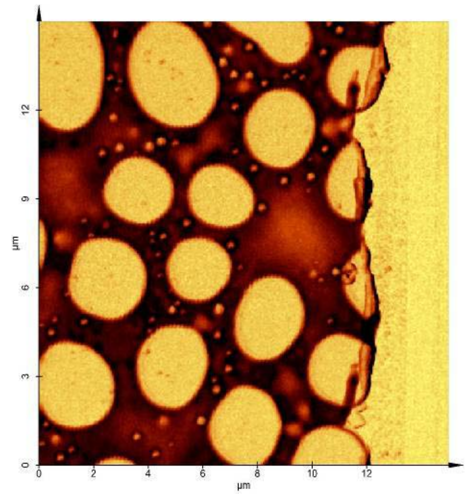
The System Response



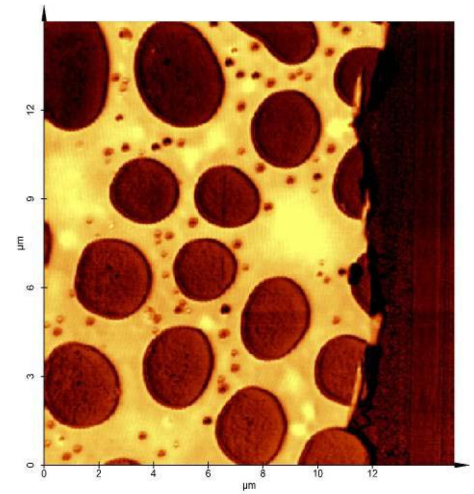
Eigenschaften ortsaufgelöst



Topographie

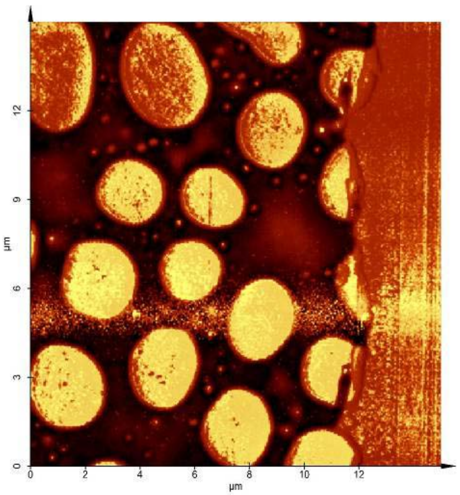


Steifigkeit

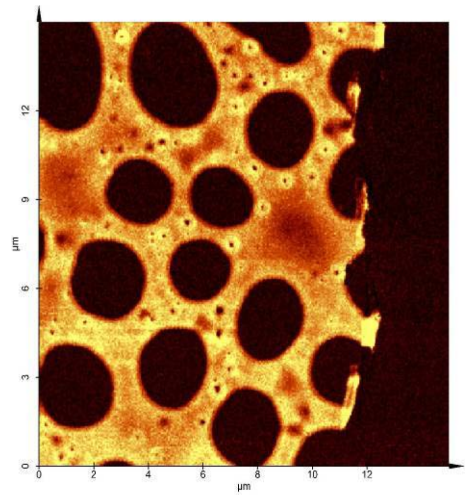


Klebrigkeit / Adhäsion

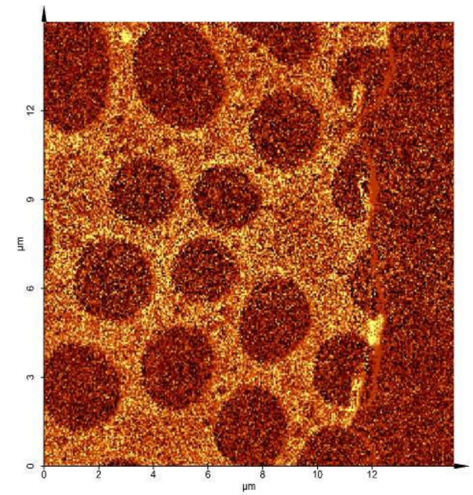
Loslöseenergie



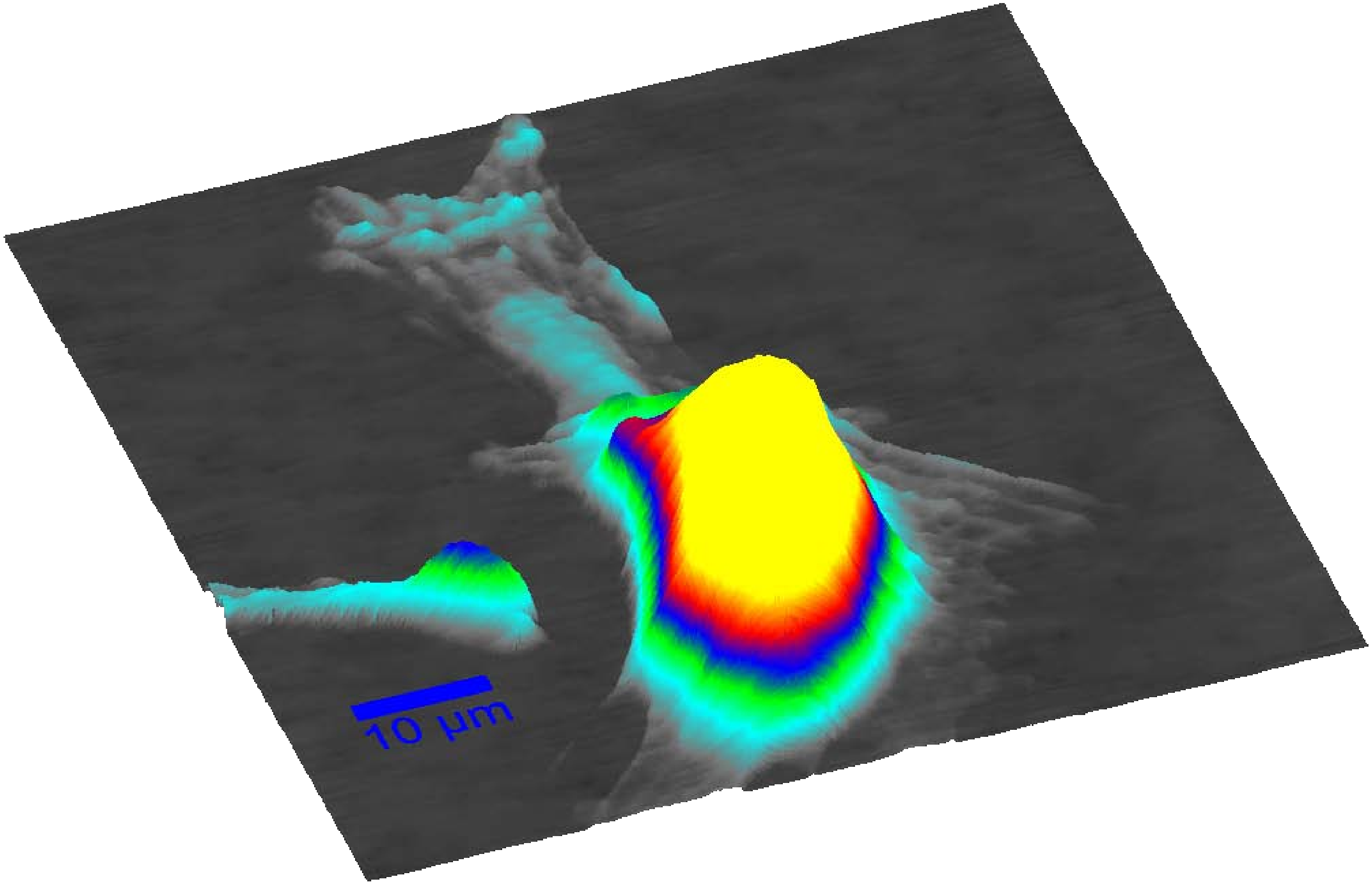
Höhe des Loslösens



Hysterese

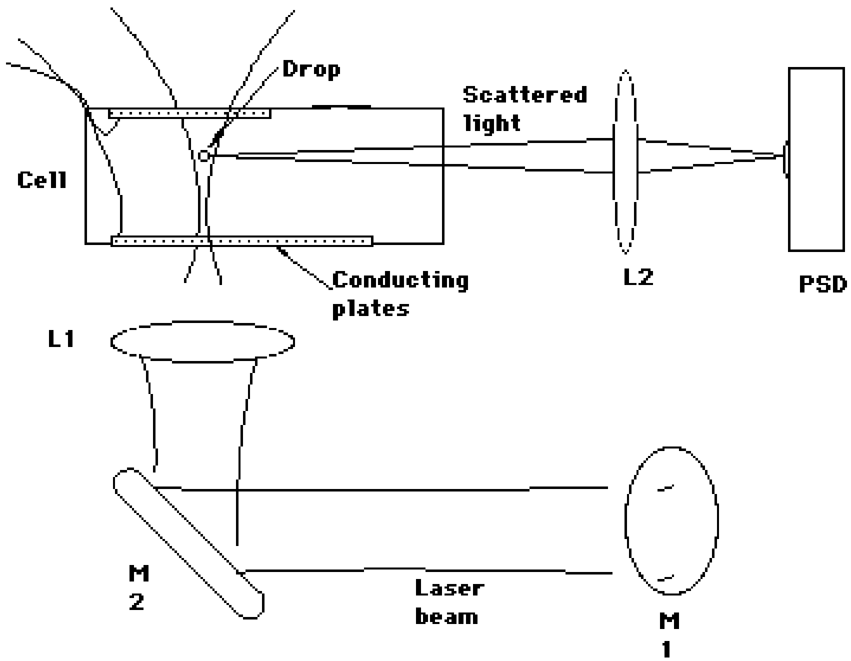


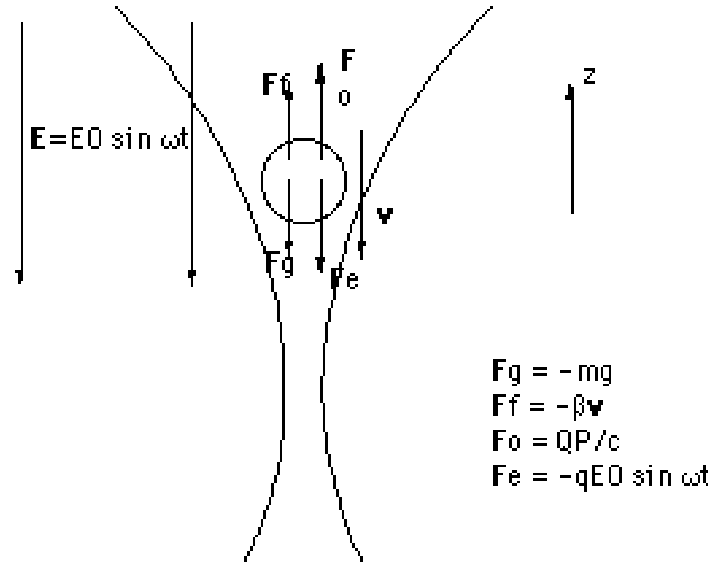
Helazelle: Topographie



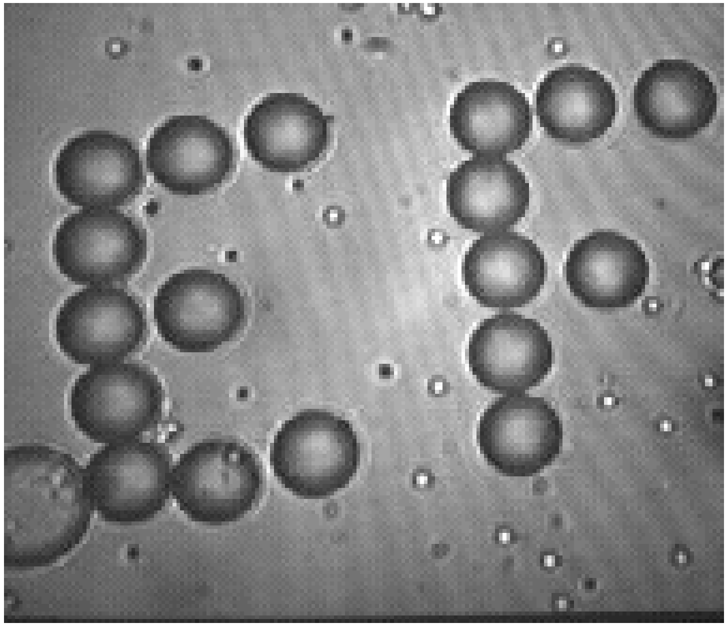
Optische Falle

Lasereinfang



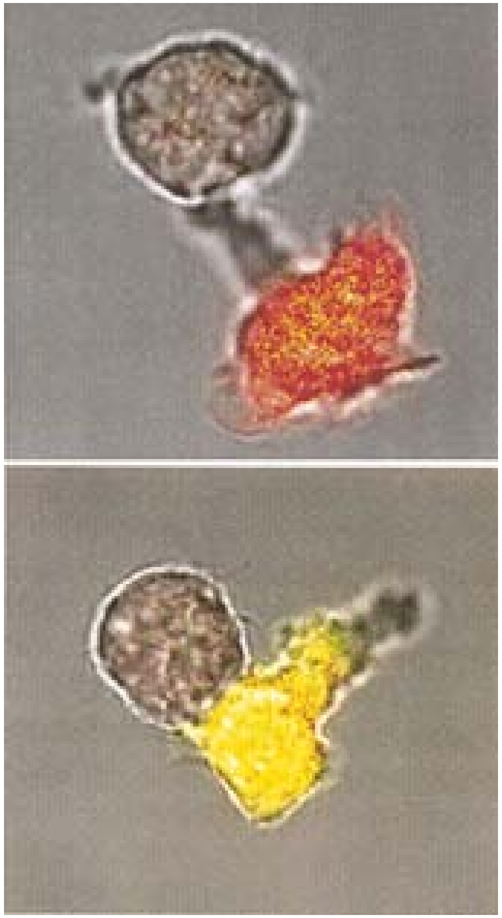


Optische Pinzette



- Manipulation von 10 µm Kugeln mit optischen Pinzetten.
- Die kleinen Kugeln im Hintergrund sind 3 µm gross.
- Gerät: 60x (N.A=0.63) Objektiv
- Universität Umea

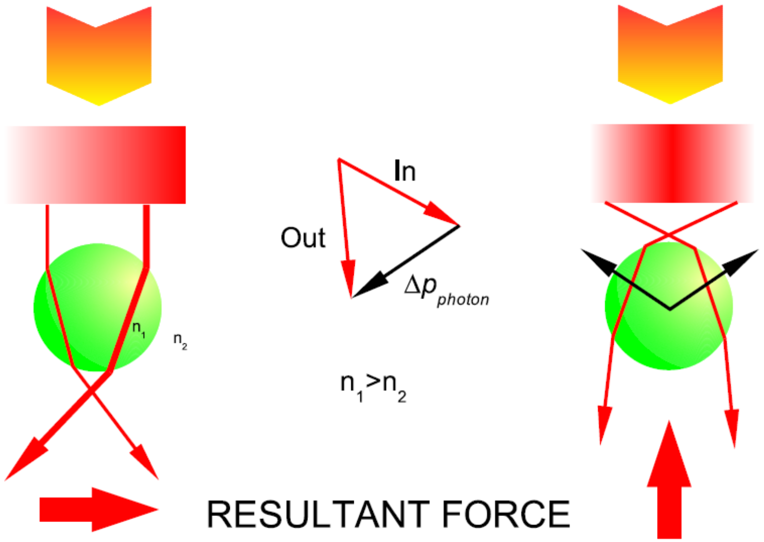
Laserpinzetten zum Einfangen von Zellen



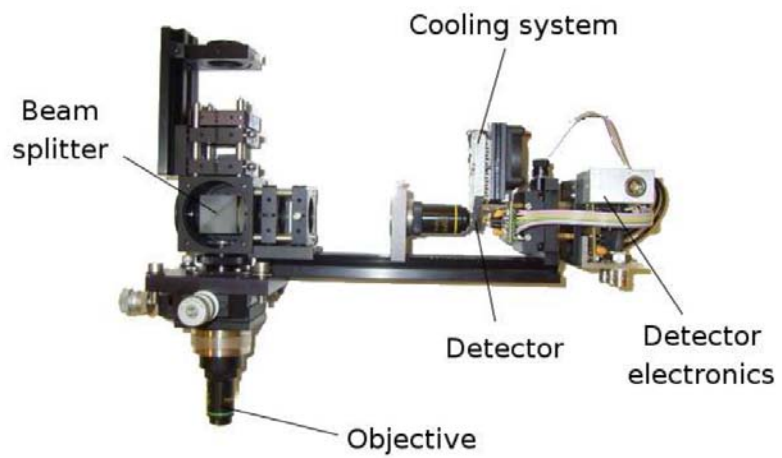
POLARITÄT VON T-Zellen

- B-Zellen lösen die Kalziumfreisetzung von T-Zellen aus
- Kalzium wird nur ausgeschüttet durch T-Zellen, wenn die B-Zellen am richtigen Ende positionniert wird.

Operating principle of the PFM



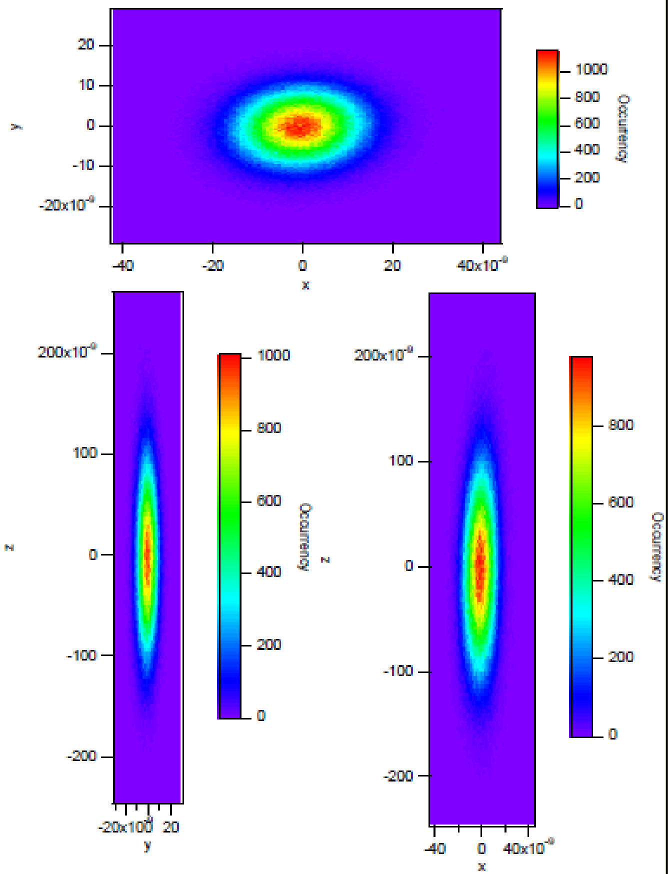
Forces:
- Optical forces
- Stochastic forces (brownian motion)
- Forces from objects
- Viscous drag forces



Laser: 1064 nm Nd-Yag
Typical forces: 100 fN to 100 pN

Nicola Maghelli, PhD Thesis Ulm University (2004)

From statistic to potential energies



Probability maps

The probability for finding a particle depemds on the local potential

Boltzmann distribution

$$p(E) = p_0 \exp\left(-\frac{E}{k_B T}\right)$$

$$p(\vec{r}) = p(E(\vec{r}))\, p_0 \exp\left(-\frac{E(\vec{r})}{k_B T}\right)$$

The probability of finding the particle anywwhere must be 1

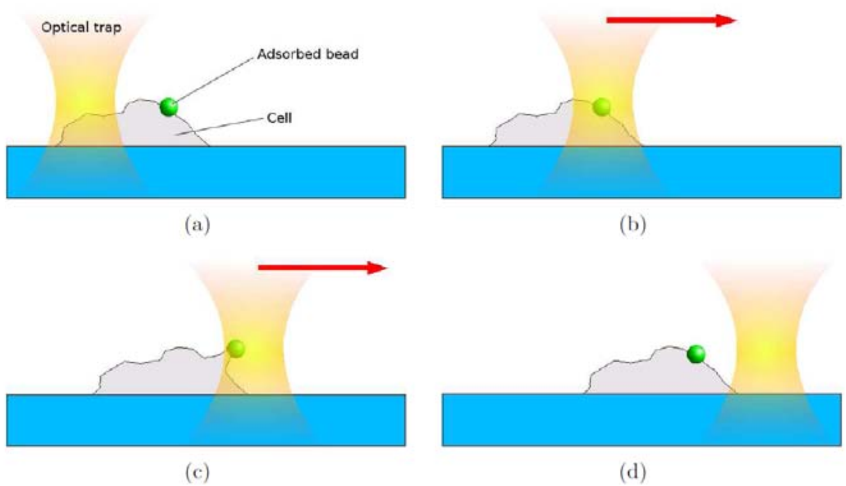
$$\iiint_{Raum} p(\vec{r})\,dV = 1 \Rightarrow p_0 = \left(\iiint_{Raum} \exp\left(-\frac{E(\vec{r})}{k_B T}\right) dV\right)^{-1}$$

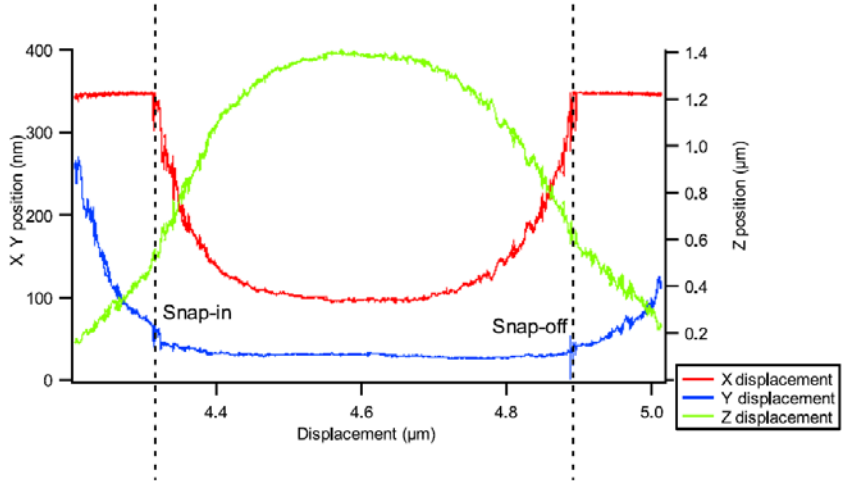
Inversion

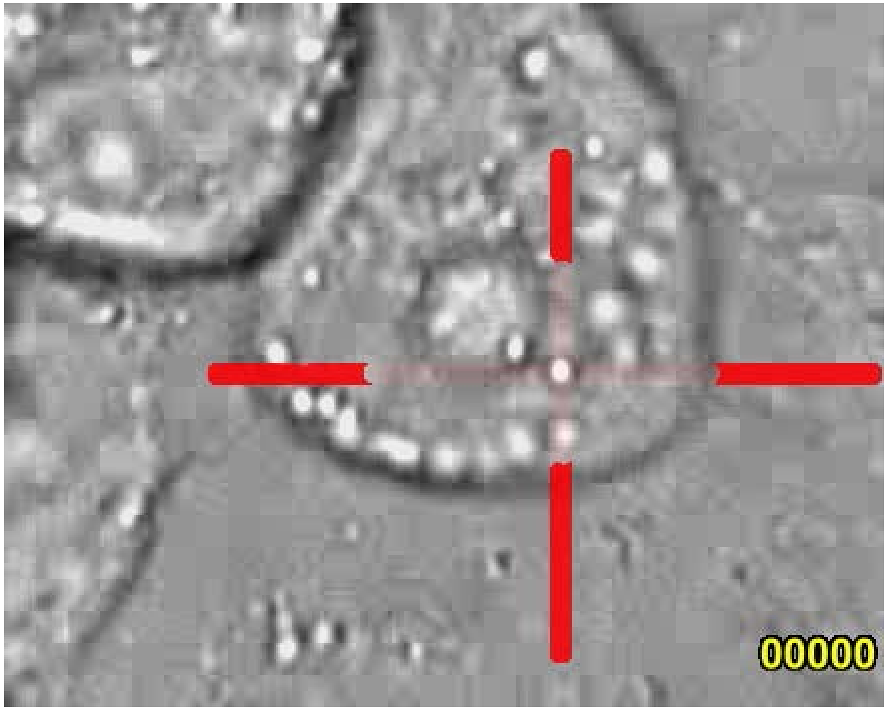
$$E(\vec{r}) = -k_B T \ln\left(\frac{p(\vec{r})}{p_0}\right)$$

Nicola Maghelli, Phd thesis Uni Ulm (2004)

Force on a particle attached to a Panc-1 cell

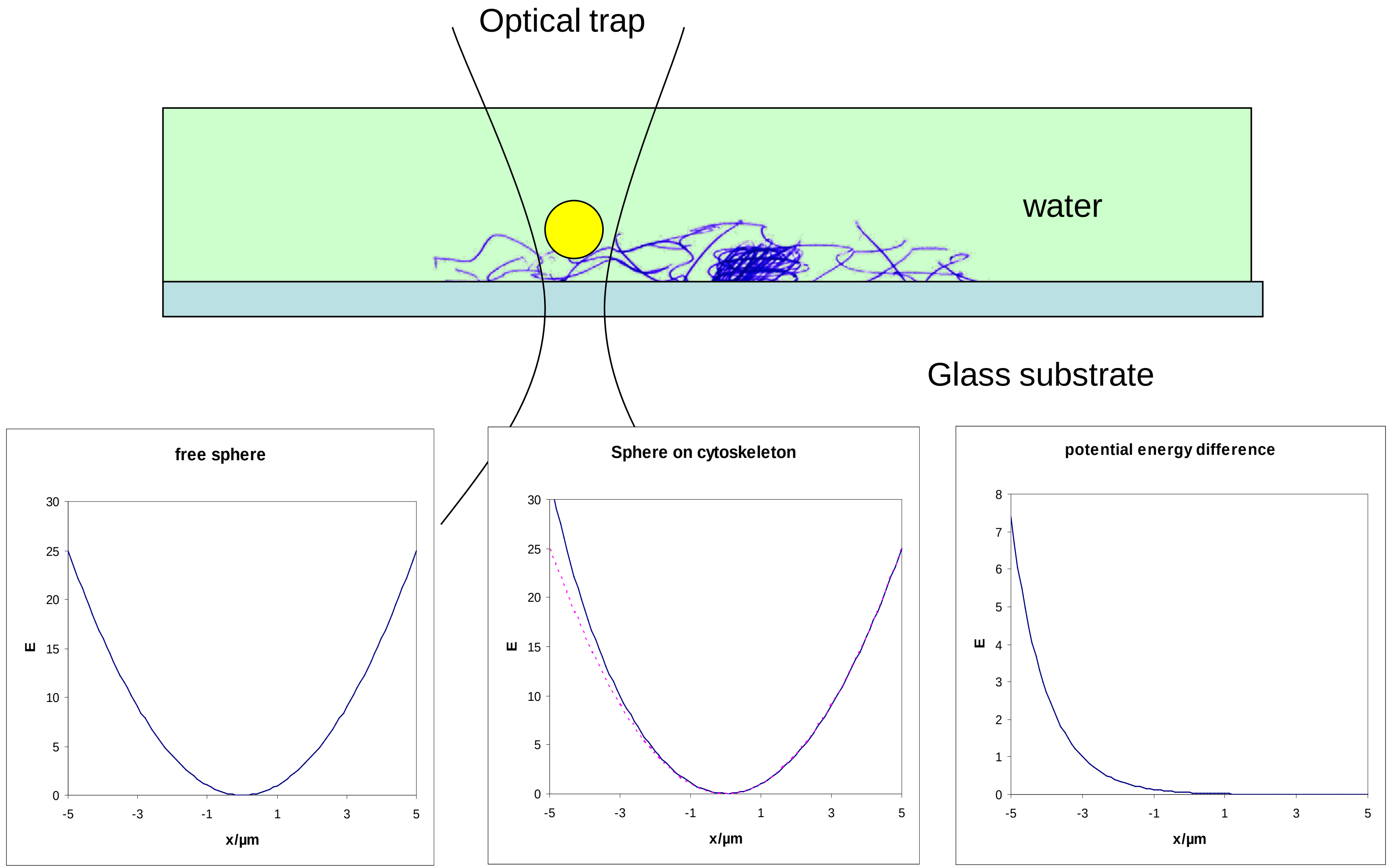


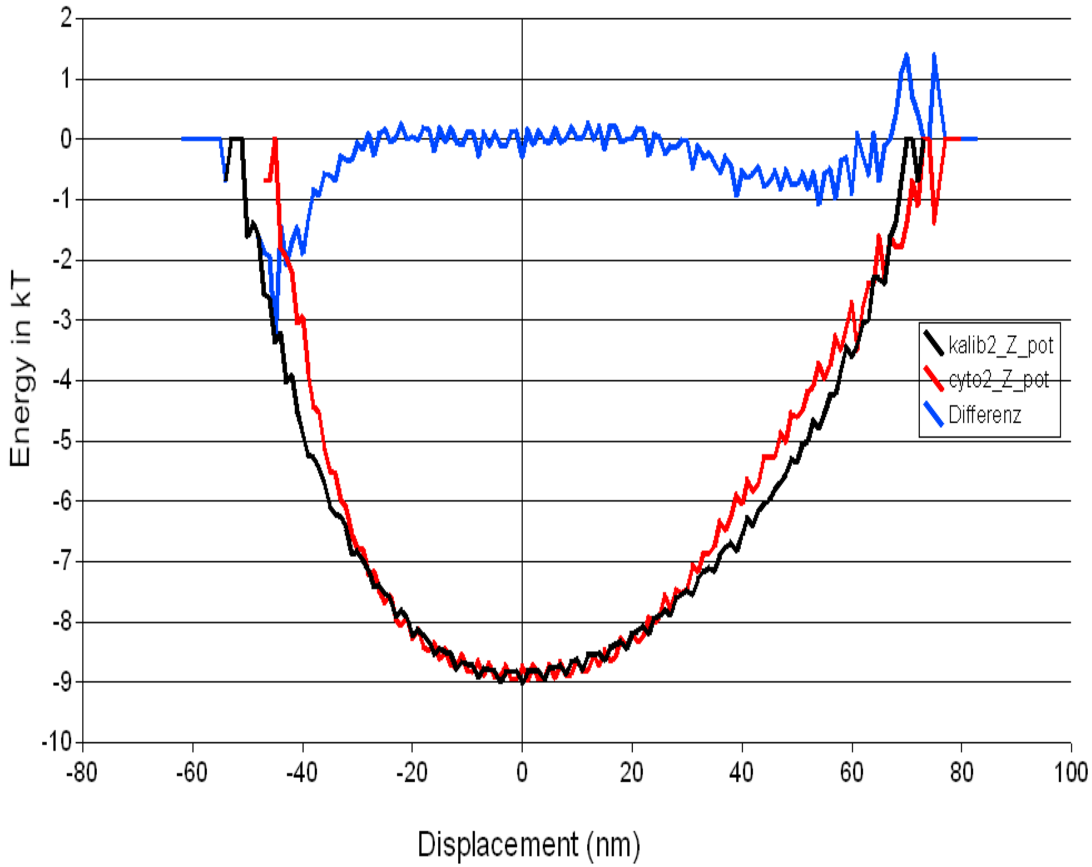




Nicola Maghelli, PhD Thesis Ulm University (2004)

Photonic Force Microscope and the cytoskeleton: a preview

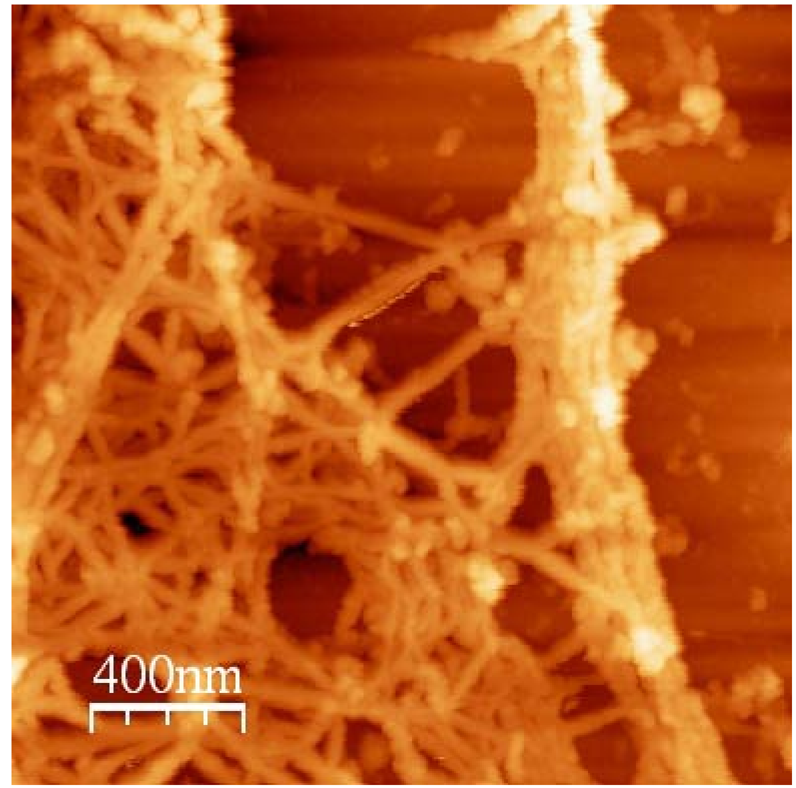




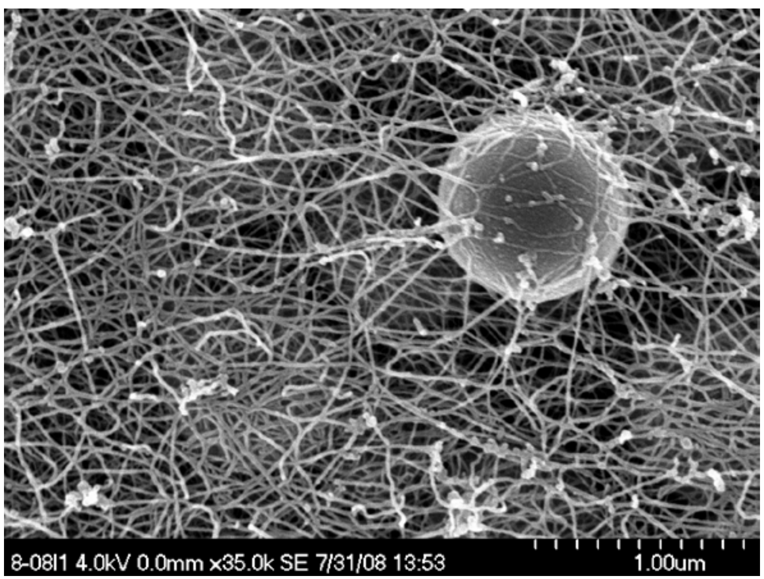
Comparison of the potential energy of a polystyrene bead in the optical tweezer in absence of the cytoskeleton (black) to the potential energy of a bead in contact with the keratin cytoskeleton (red) The difference (blue) shows the inverted potential of the network. The curvature of the blue curve is proportional to Young’s modulus of the network.

Cell extraction

- Carcinoma Cells, line Panc 1, incorporate the beads
- Extraction see Beil et al 2003



AFM picture of the extracted cytoskeleton



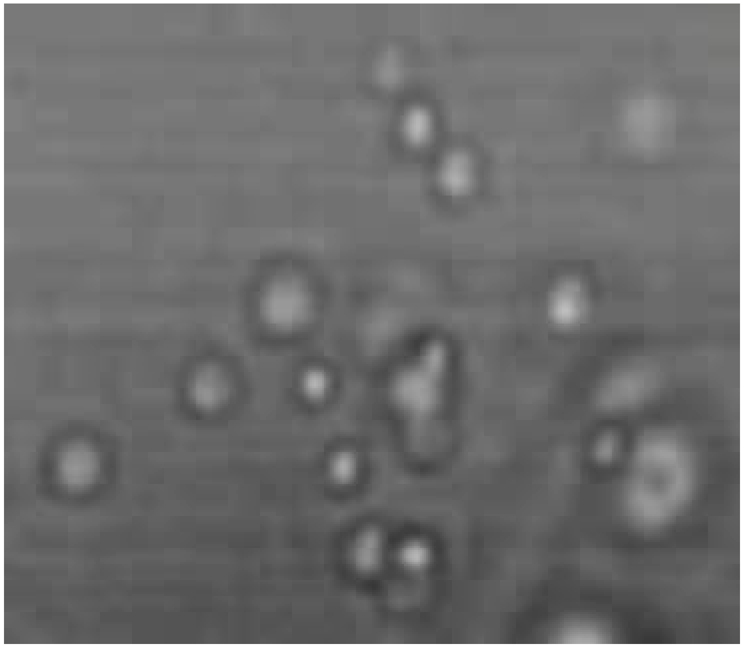
EM picture of the extracted cytoskeleton

(Zentrale Einrichtung Elektronenmikroskopie, Universität Ulm)

Brownian motion

Size 16x16 µm^2

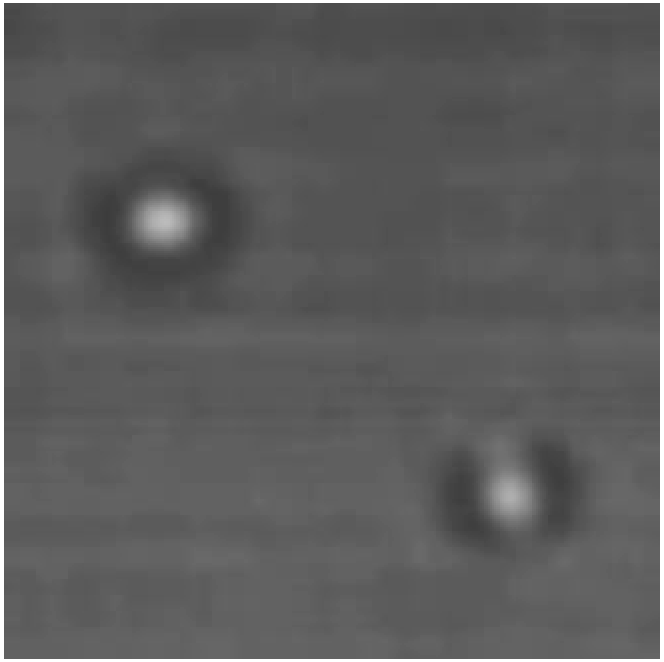
Free particle



Particles in an extracted keratin cytoskeleton

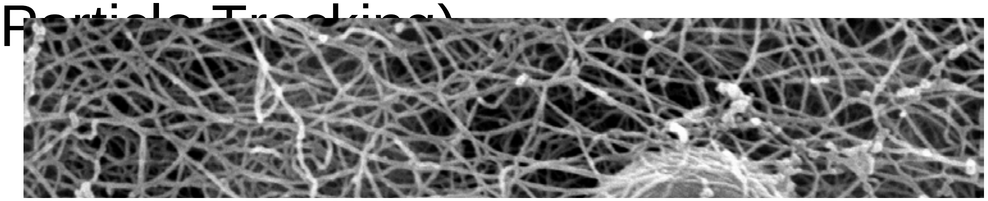
Keratin gel

Size 16x16 µm^2



Review of the first talk and introduction

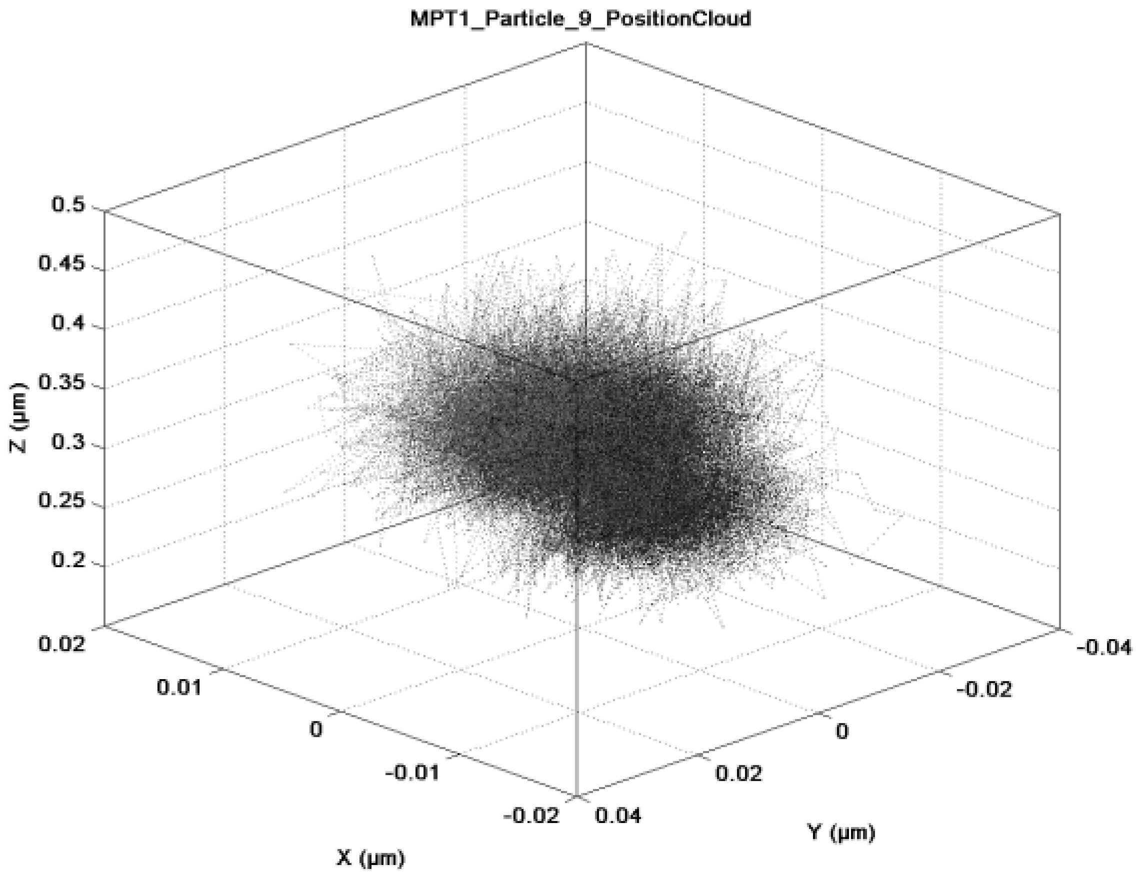
- Microrheology: (Multiple Particle Tracking)



  - Beads:
    + Size: 500nm,
    + Embedded in
      (via phagocytos
    + Brownian moti
  - Camera and Ma
    + Frequency: 50
    + Particle Tracki

→ Model for gatheri

→ Mason 1995, 200



Comparison of filament networks

- Extracted Panc1 cytoskeleton

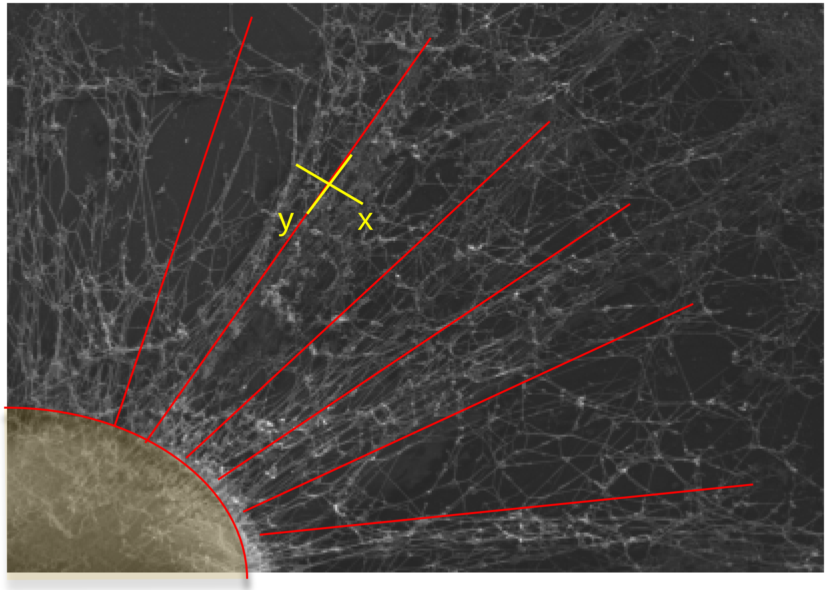
  - Measurement data:
    + Frequency: 5000Hz

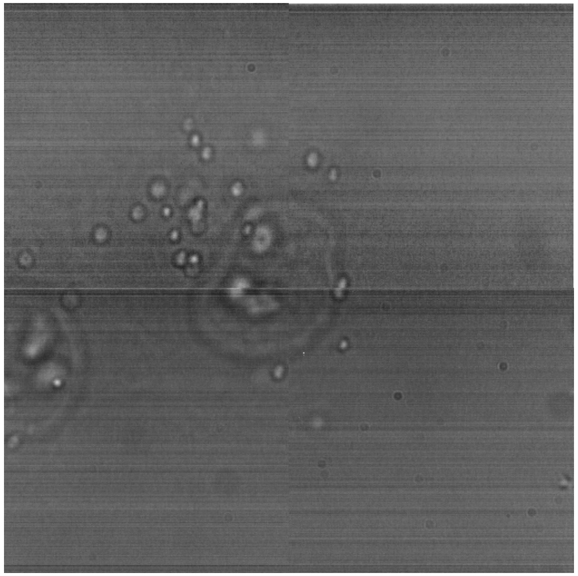
    + Bead Size: 500nm, 1µm

    + Transformation of coordinates to a radial arrangement

    + Picture Size 256x256 pixel

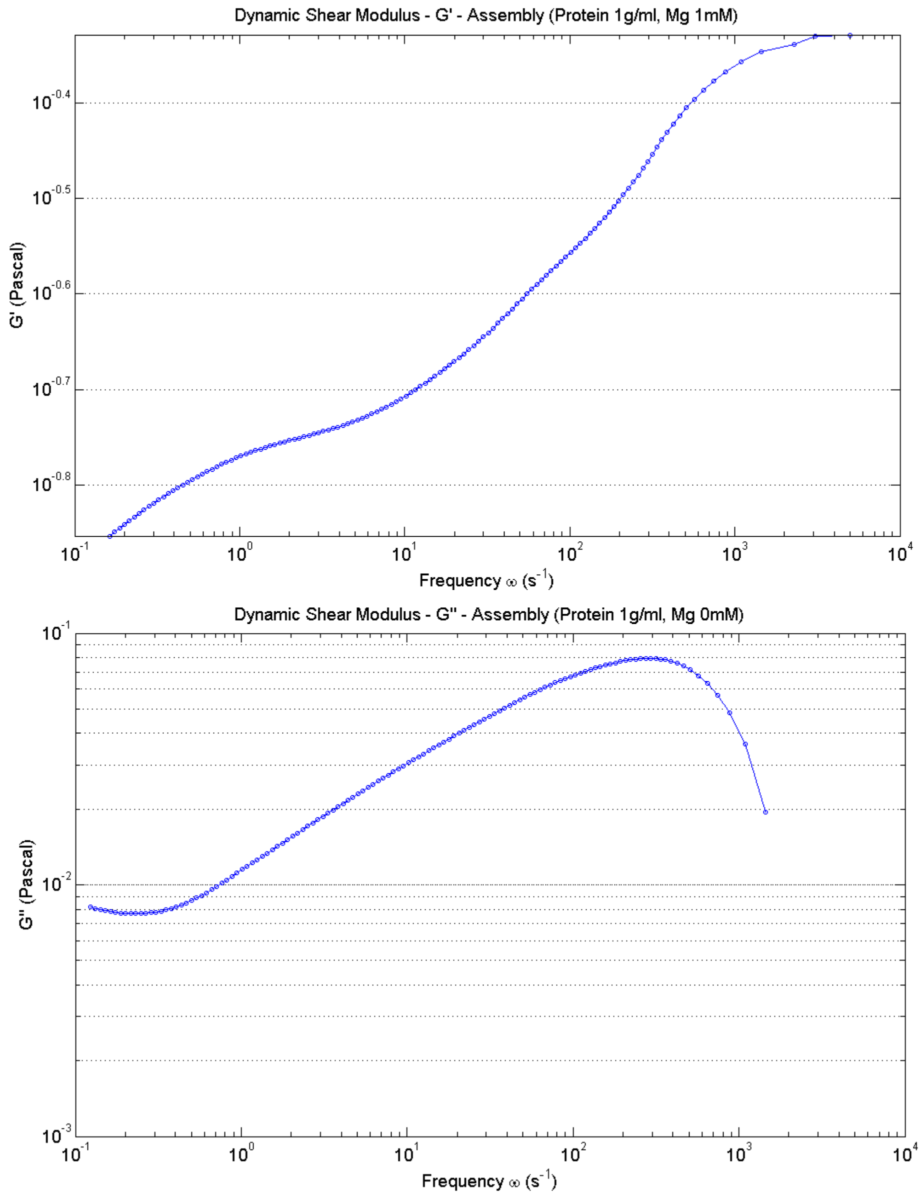
    + 4 Measurements for each cell
    → larger time window
    → lower frequencies at computation can be measured





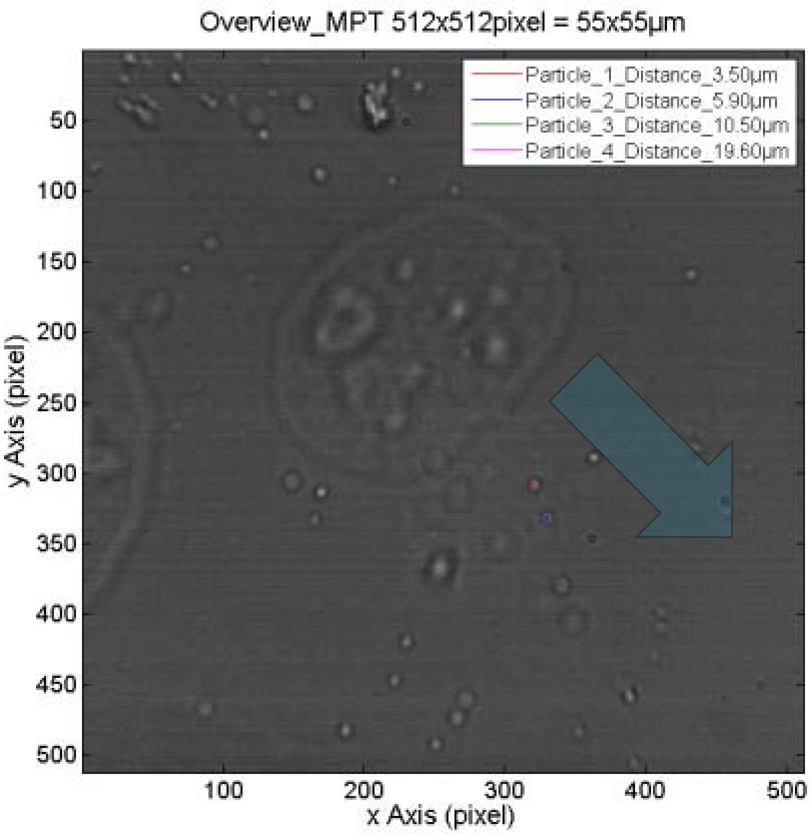
Comparison of filament networks

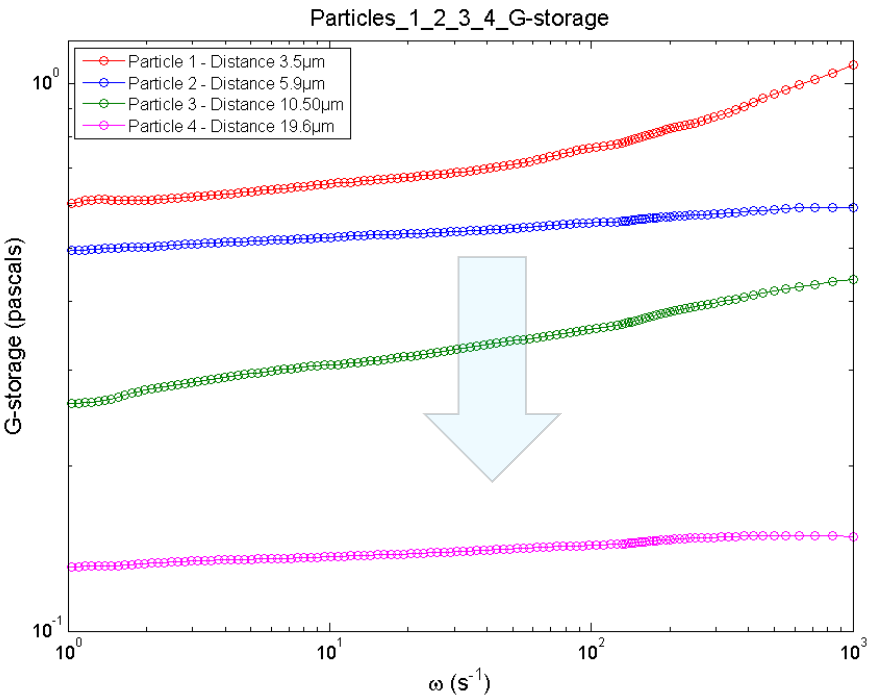
- Assembled keratin 8/18 networks
  - + G' between 10^{-1} and 1 Pascal
  - + G'' between 10^{-2} and 10^{-1} Pascal

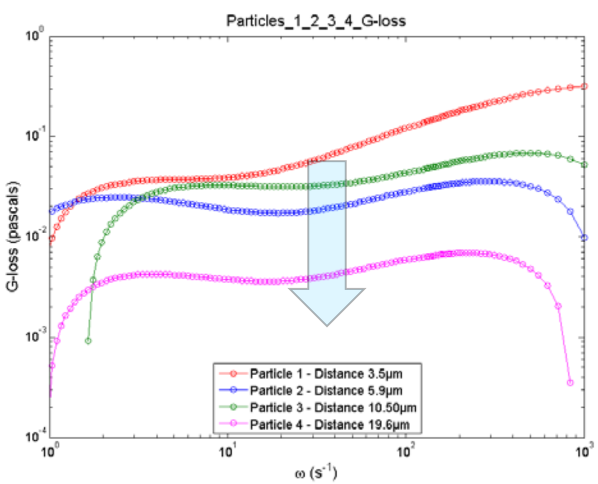


Comparison of filament networks

- Extracted Panc1 cytoskeleton
  - Example:





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PHOTOSYNTHESIS
THE BIG BANG
BUILDING THE BETTER MOUSE TRAP
EARTH
SUN
NAME
GEOLOGICAL FORMATIONS
HOW TO GROW CRYSTALS
STEP #1
STEP #2
STEP #3
Nick Downes

ulm university universität ulm

Danke!

Fragen? Aber sicher!