Nanotechnology

7th lecture

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Scanning Probe Microscopy across dimensions

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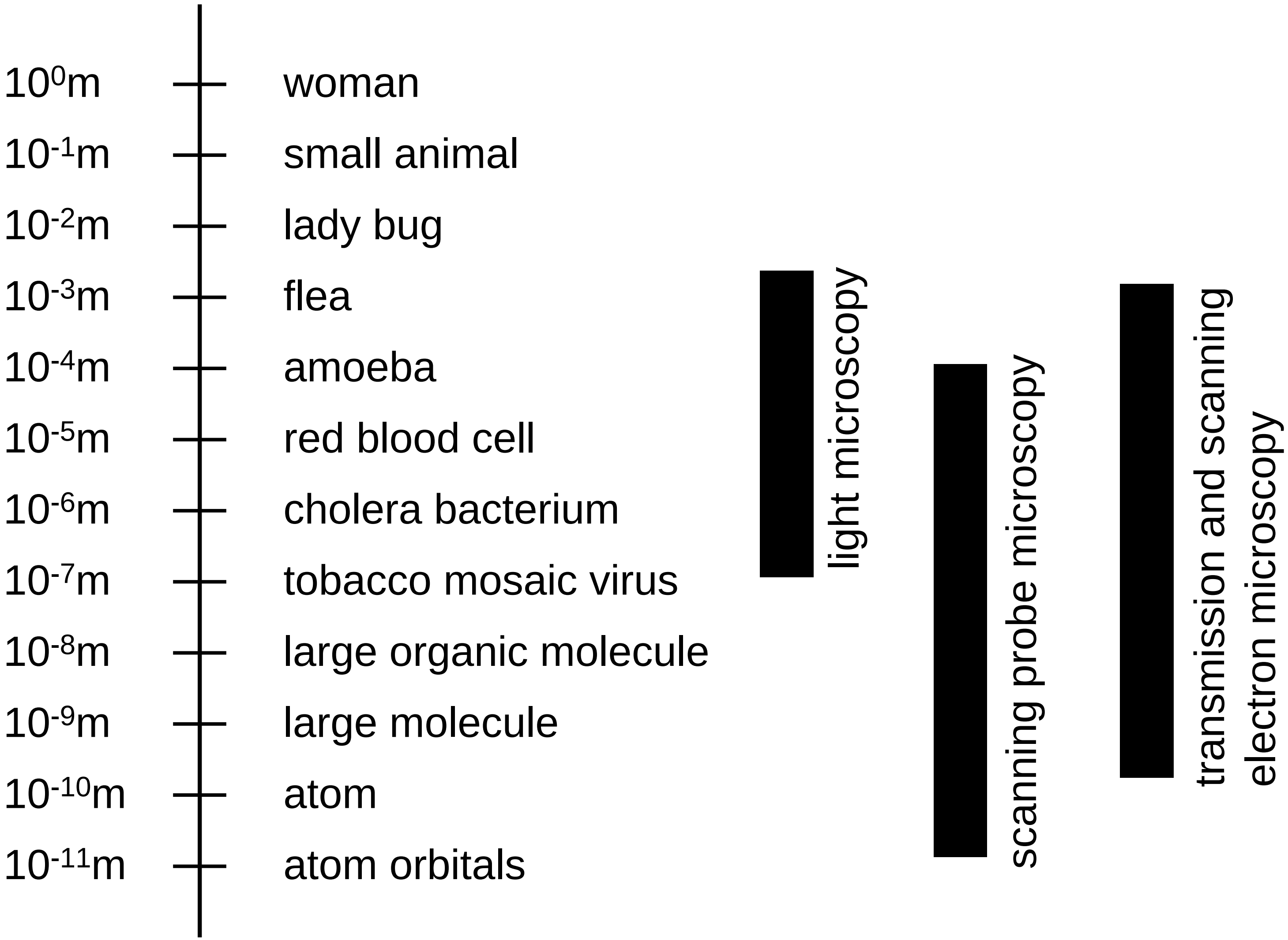
IAP

AC²T research

Austrian Center of Competence for Tribology
Österreichisches Kompetenzzentrum für Tribologie

TU WIEN

Technische Universität Wien
Vienna University of Technology

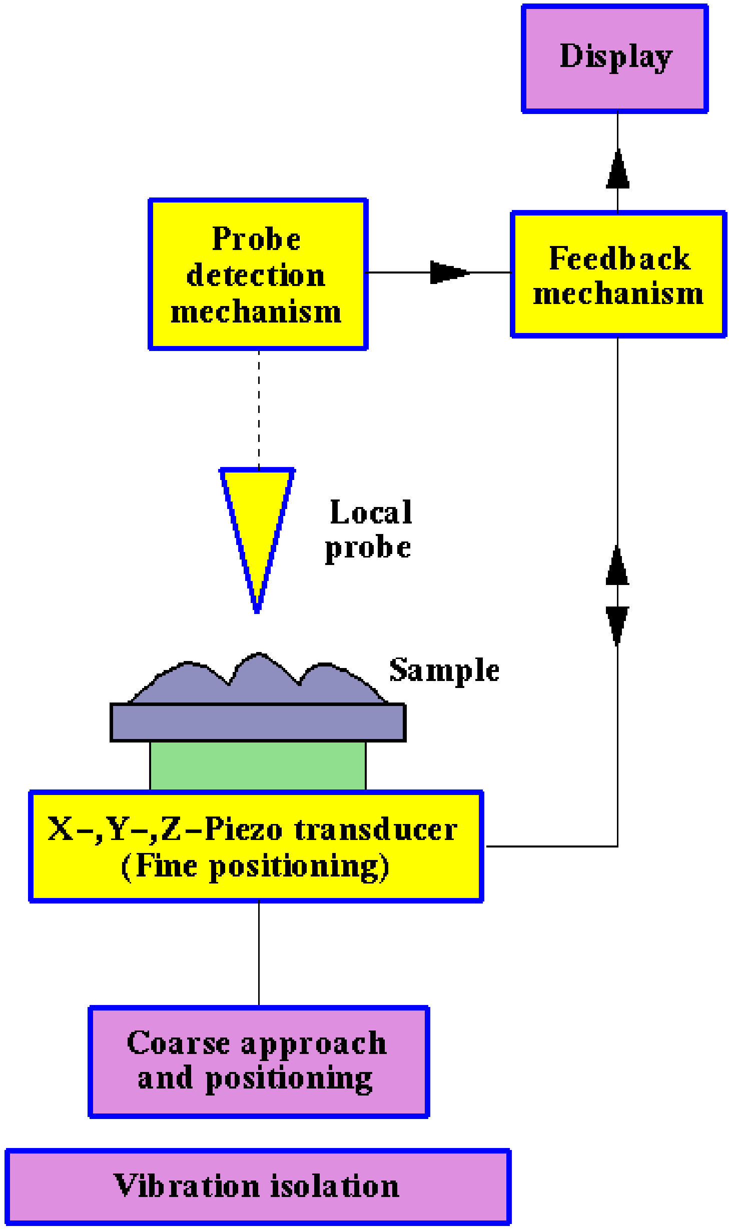


10^0m woman
10^-1m small animal
10^-2m lady bug
10^-3m flea
10^-4m amoeba
10^-5m red blood cell
10^-6m cholera bacterium
10^-7m tobacco mosaic virus
10^-8m large organic molecule
10^-9m large molecule
10^-10m atom
10^-11m atom orbitals
light microscopy
scanning probe microscopy
transmission and scanning electron microscopy

- **SPM methods**
- **Cells**:
  - Diatoms
  - Short excursion to biogenic adhesives
  - Biotribology
- **Single molecules**
  - Chaperonins: Probing protein-protein interactions in real time
- **Atoms**
  - Nanostructuring atomically flat surfaces with ions
  - Ion bombardment of atomically flat crystals
- **Subatomic features**
  - Atom orbitals
  - Electron spins

Some SPM methods

Generalized scheme of an SPM

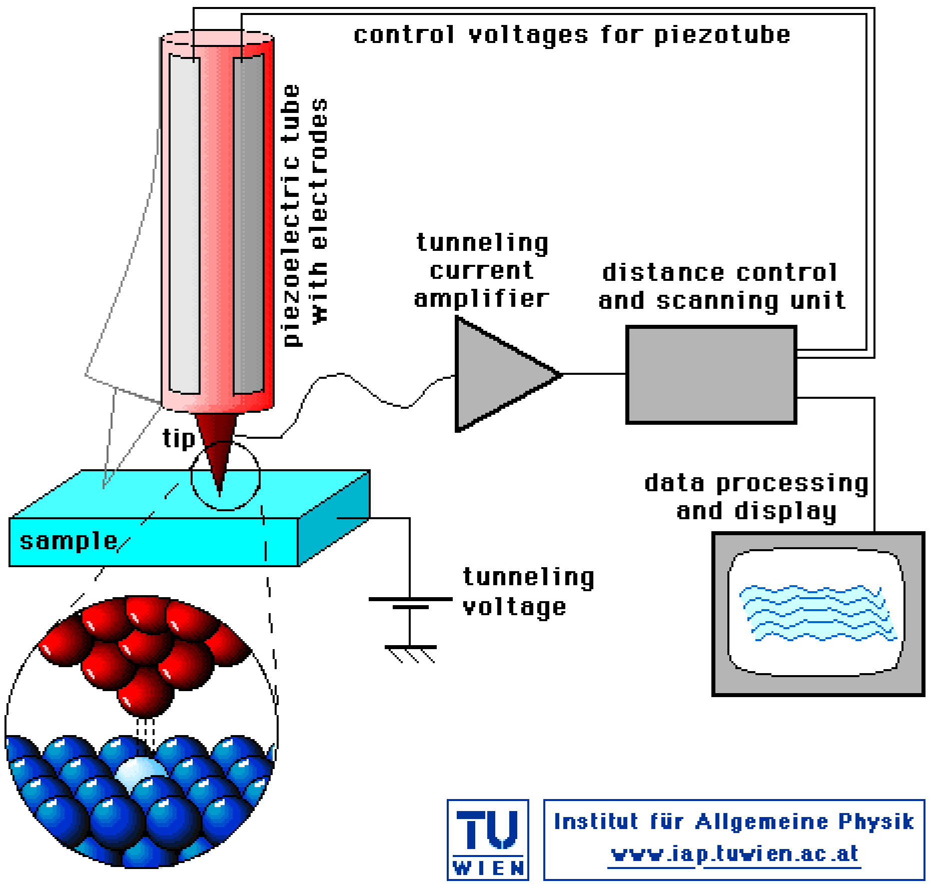


A scanning probe microscope (SPM) **raster scans** a sharp probe over a surface.
The mechanical, electrical, magnetic, optical and chemical interaction between the **sharp probe** and the **surface** provides a 3D representation of surface parameters at or near the atomic scale. The samples can be in **air**, **vacuum**, or immersed in some **liquid**.

Some types of SPMs

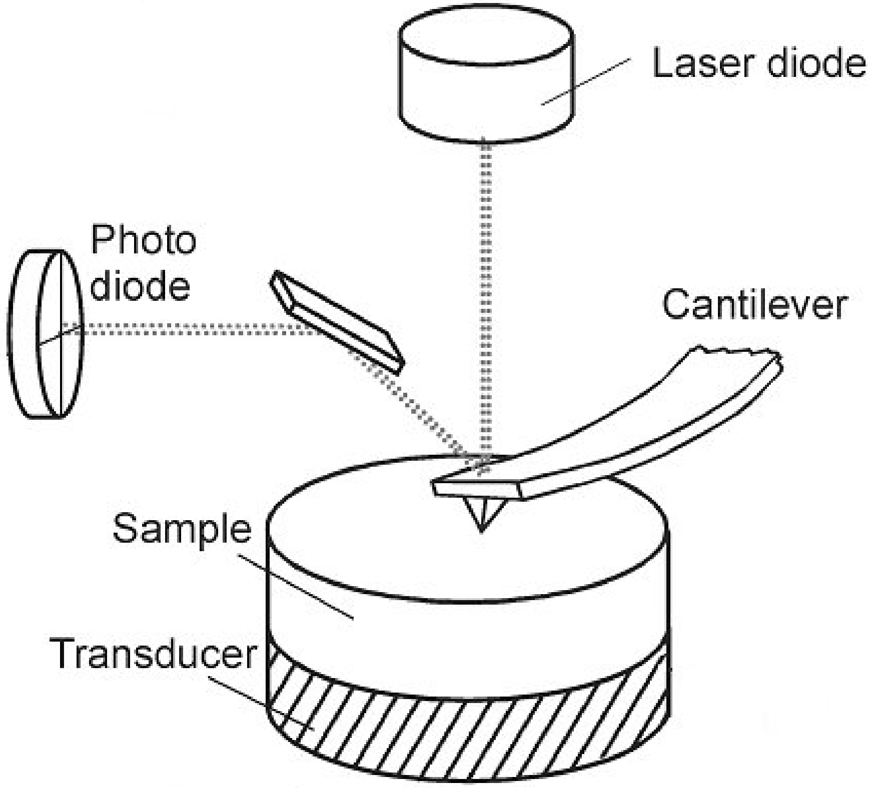
- Scanning tunneling microscopy (STM, 1982)
- atomic force microscopy (AFM, 1984)
- scanning near field optical microscope (SNOM, 1986)
- magnetic force microscope (MFM)
- magnetic resonance force microscope (MRFM)
- scanning thermal microscope
- scanning potentiometry microscope
- ballistic electron emission microscope (BEEM)
- scanning capacitance microcope
- scanning ion conductance microscope (SICM)

Scanning Probe Microscopes: Scanning Tunneling Microscopy



The **STM** measures a weak electrical current flowing between tip and sample (**tunneling current**).

Scanning Probe Microscopes: Atomic Force Microscopy

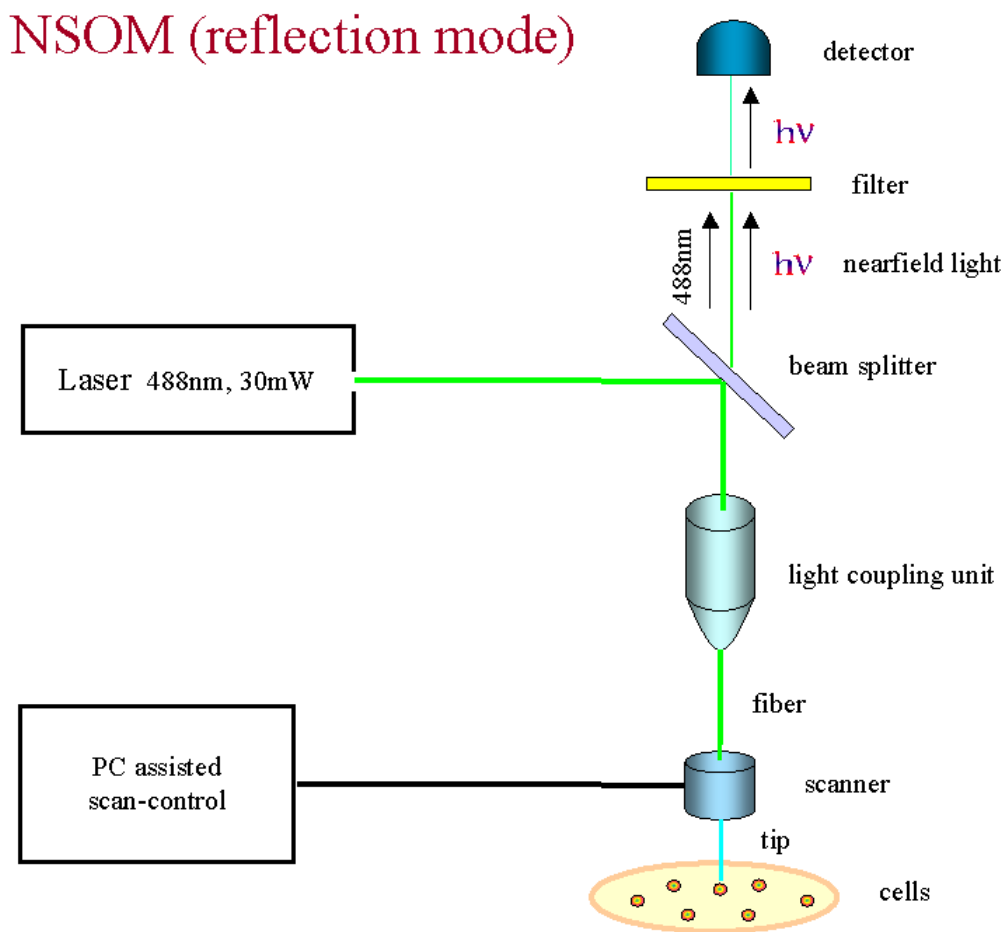


- The **AFM** measures the interaction **force** between the tip and surface.
- The tip may be dragged across the surface, or may vibrate as it moves.

AFM operational modes

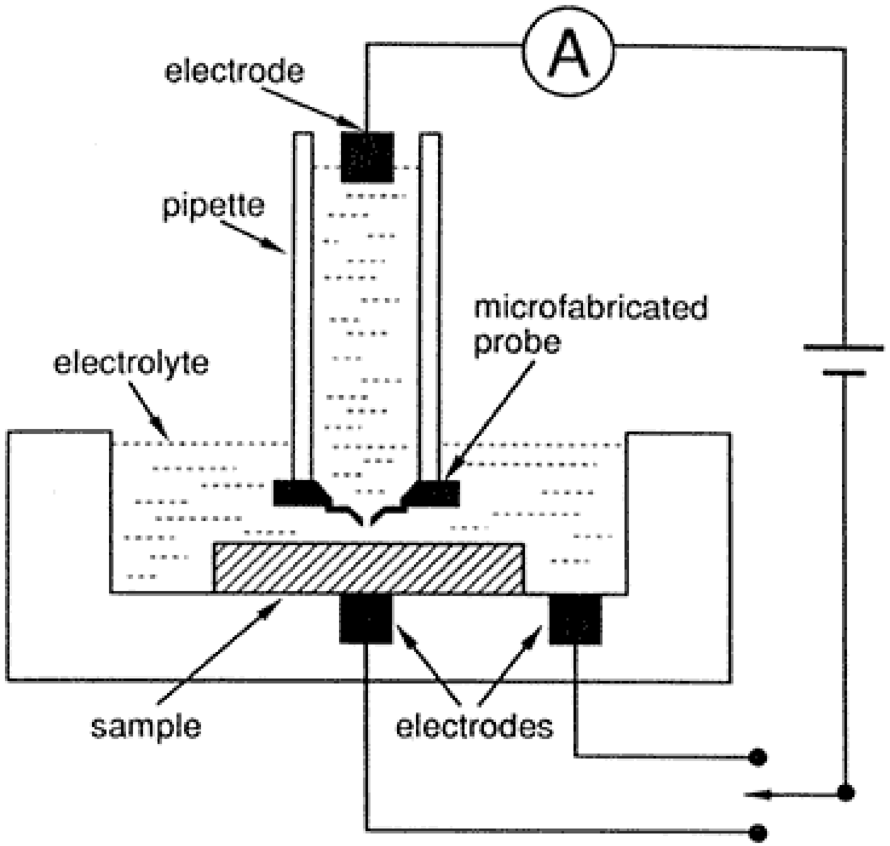
- **Contact mode**
- **Non-contact mode**
- **Intermittent mode**
- **Phase imaging**

Scanning Probe Microscopes: Scanning Near Field Optical Microscopy



- The **NSOM** scans a very small **light** source very close to the sample.
- Detection of this light energy forms the image.
- NSOM can provide resolution below that of the conventional light microscope.

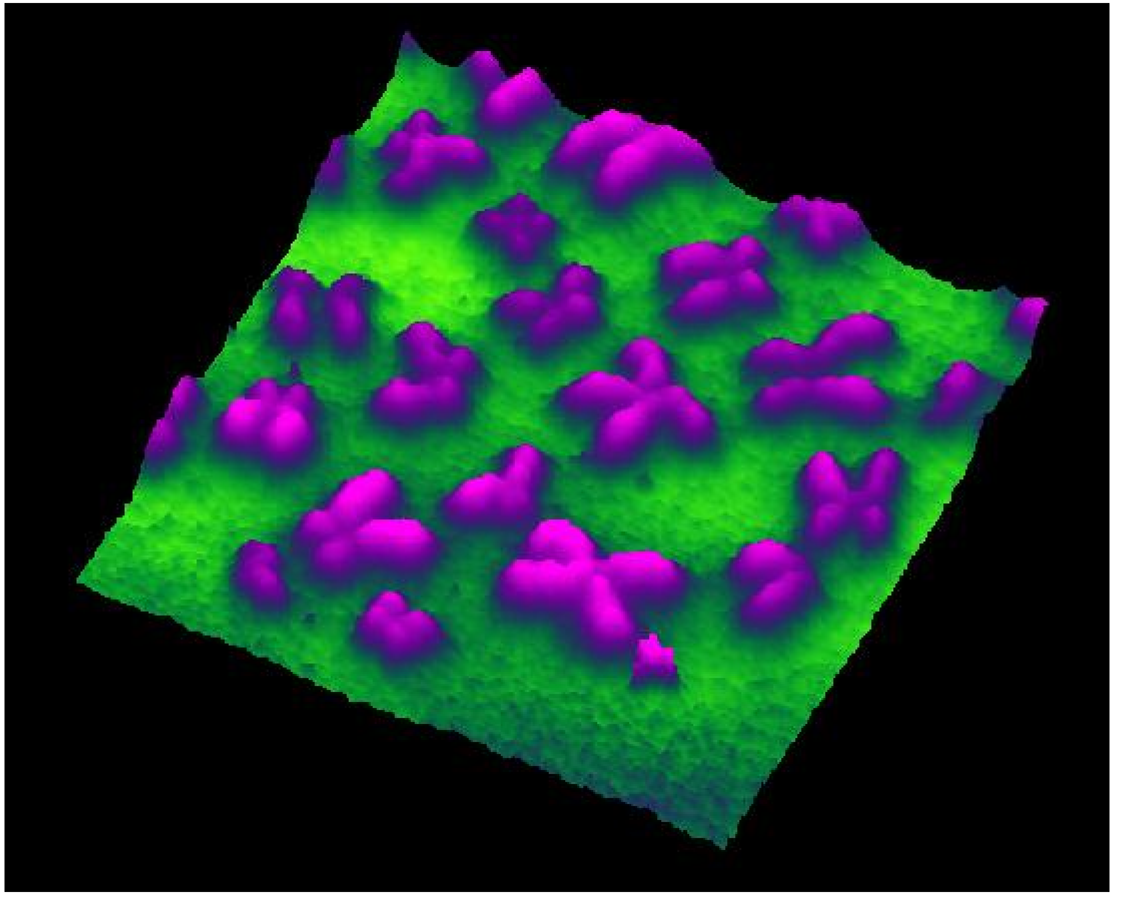
Scanning Probe Microscopes: Scanning Ion Conductance Microscopy



- The **SICM** measures the **ion current** between two electrodes, one in a **sharp glass needle**, one in the **bath solution**.
- Resolution: half the diameter of the pipette. Great for biological samples.

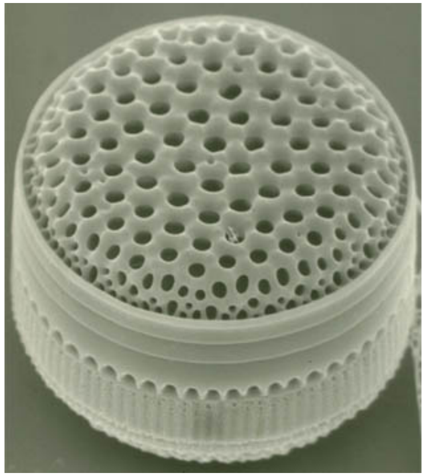
Human Chromosomes

AFM, 20·20 μm^2



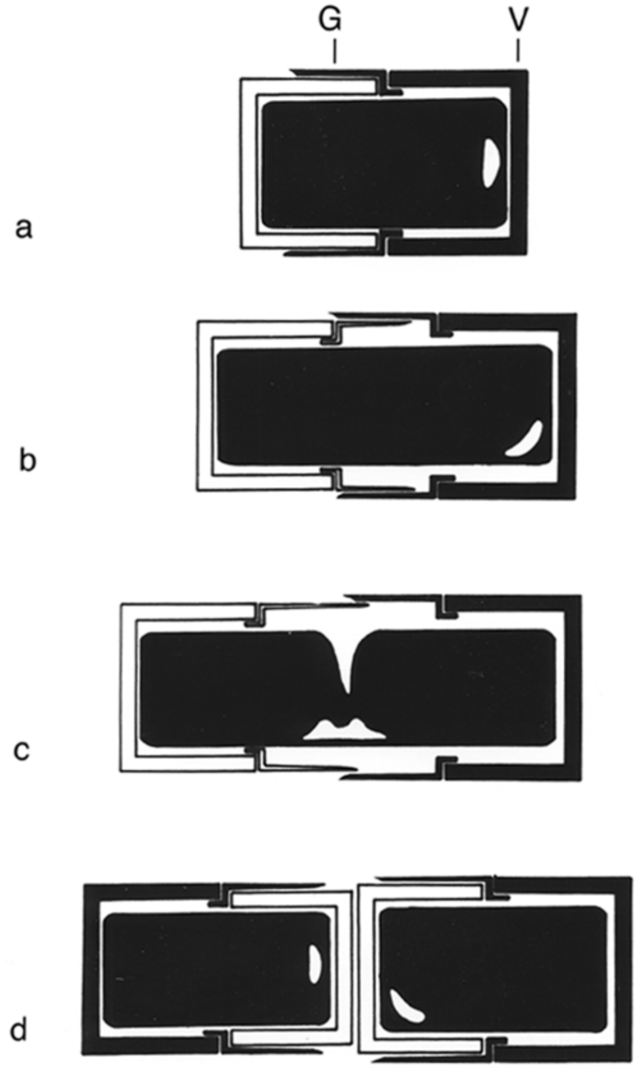
Cells

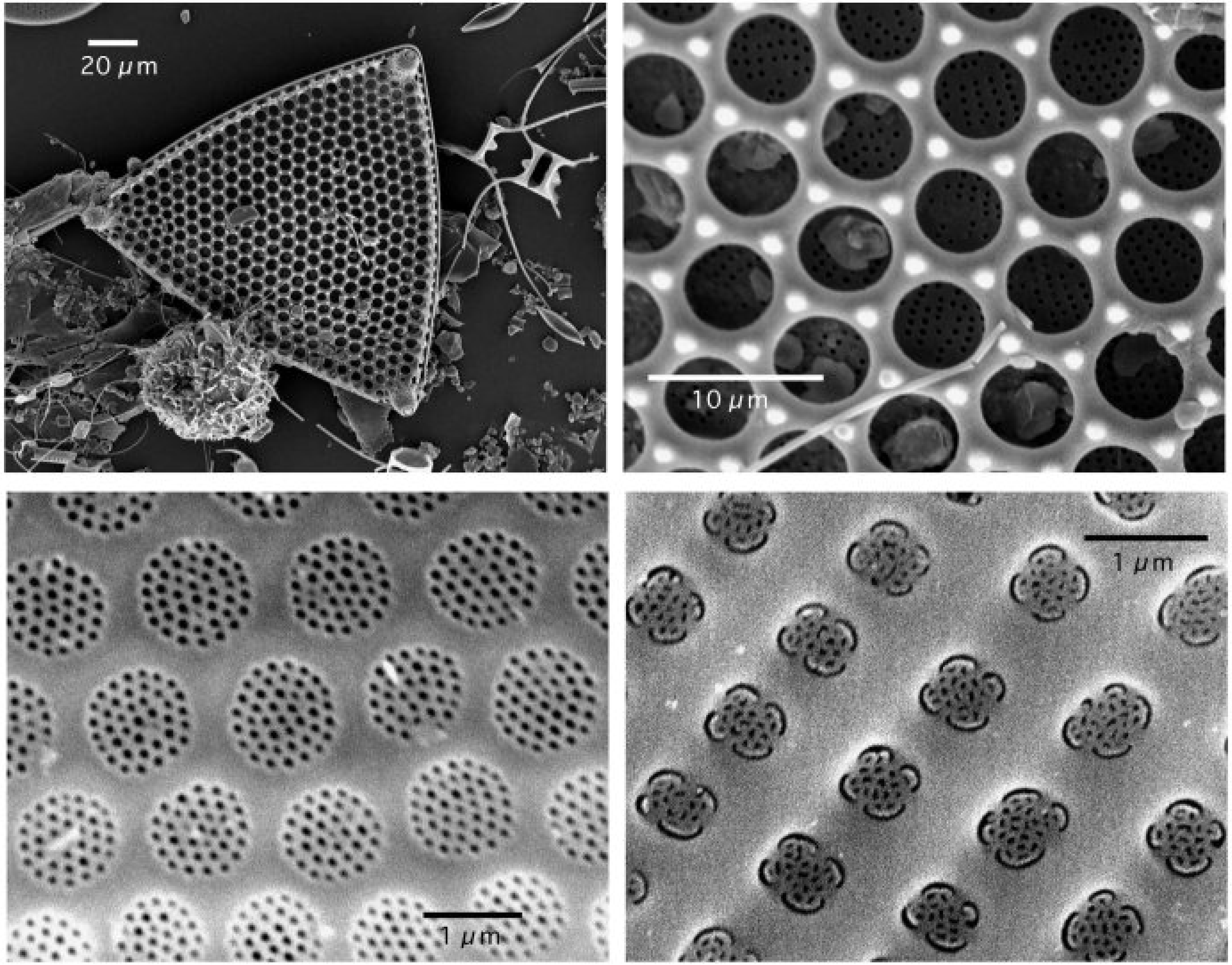
Cells: Diatoms



© W. Oschmann

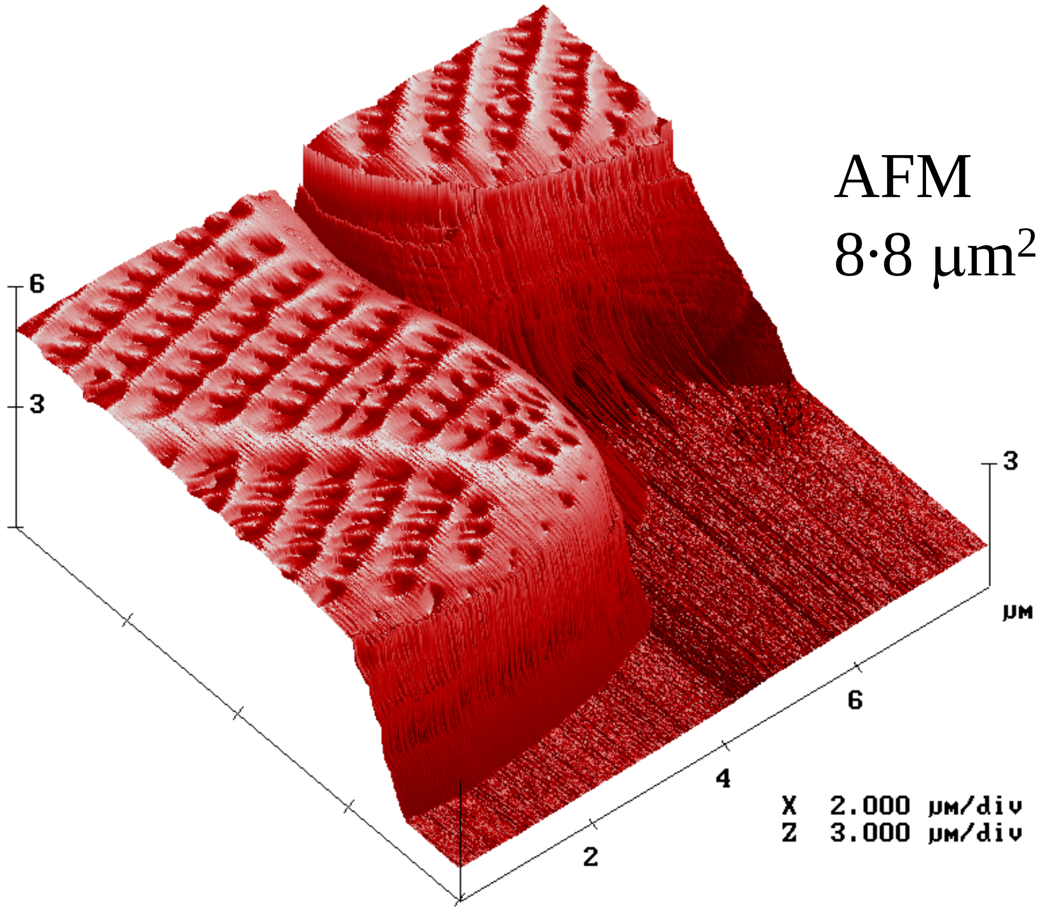
- **Single cellular** organisms
- Size: some **micrometers**
- 10 000s different species
- Reproduce via cell division
- Under ideal conditions, within ten days the offspring of one single cell number one billion cells (assembly line production of **nanostructures**)
- Surfaces made from **amorphous glass**


G
V
a
b
c
d



Top: *Tricaeratium favus*, bottom left: *Roperia tessellata*,
bottom right: *Achnathes brevipes* © Gebeshuber *et al.*, J. Mat. Sci. 2002

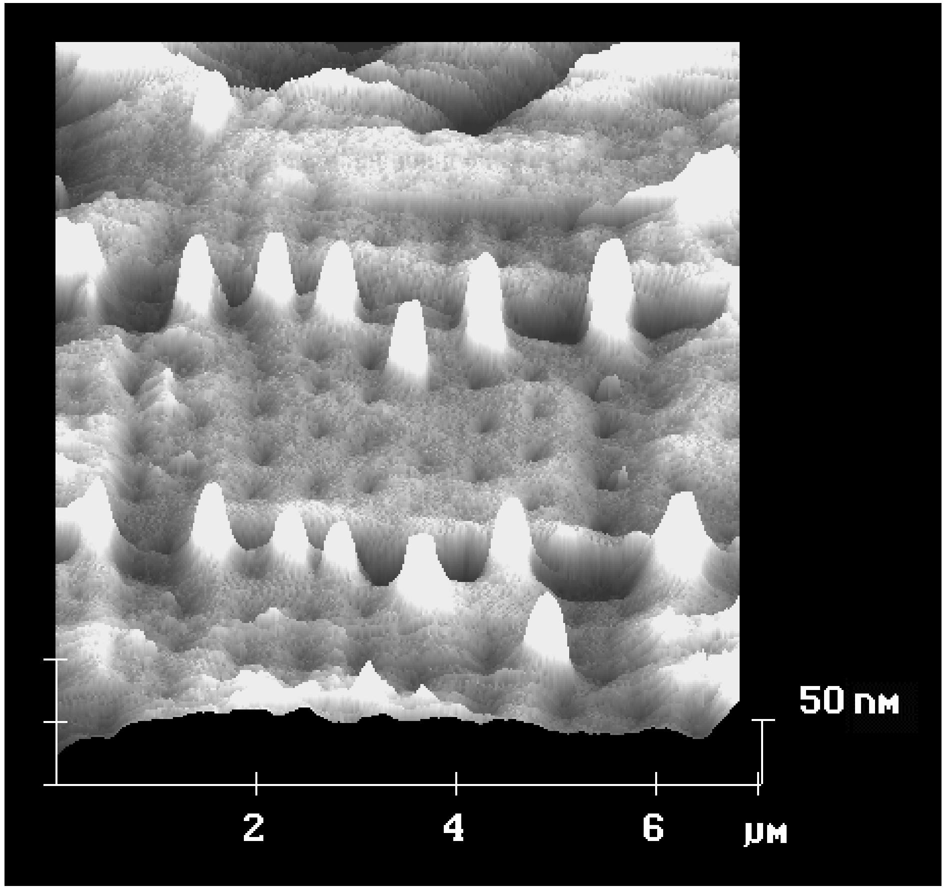
AFM of Living Cells: Diatoms I



AFM
8·8 µm²

Gebeshuber I.C. *et al.* (2003) *"Atomic force microscopy study of living diatoms in ambient conditions"*, J. Microsc. Oxf. **212**, pp. 292-299.

AFM of Living Cells: Diatoms II

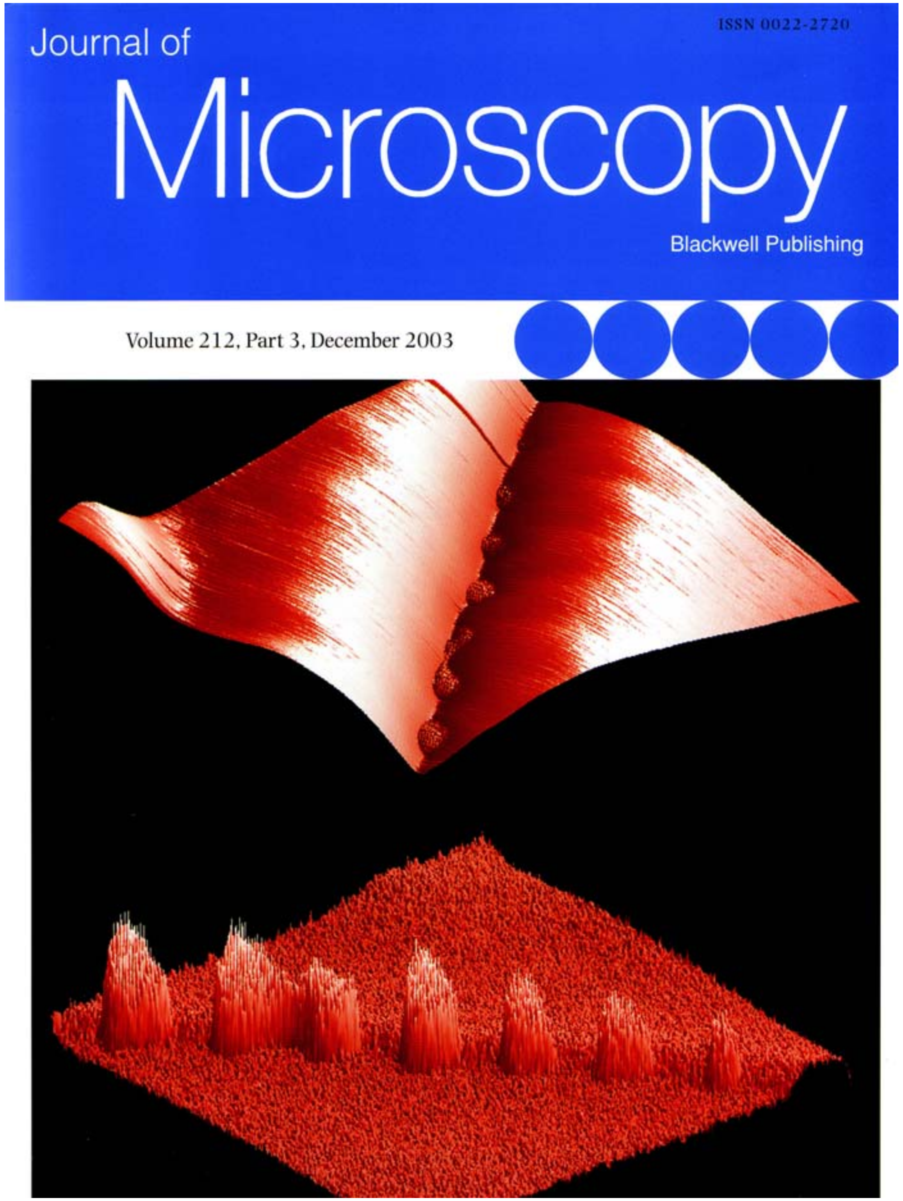


Gebeshuber I.C. *et al.* (2003) *"Atomic force microscopy study of living diatoms in ambient conditions"*, J. Microsc. Oxf. **212**, pp. 292-299.

Underwater Adhesives (AFM)

- Most **man made adhesives fail** to bond in wet conditions, owing to chemical modification of the adhesive or its substrate.
- **Engineering** strong and robust underwater **adhesives** that are stable in wet environments are a **challenge** to current technology.
- **Diatoms produce excellent underwater adhesives**.
- Diatoms living close to the poles of the earth produce **ice binding molecules**.

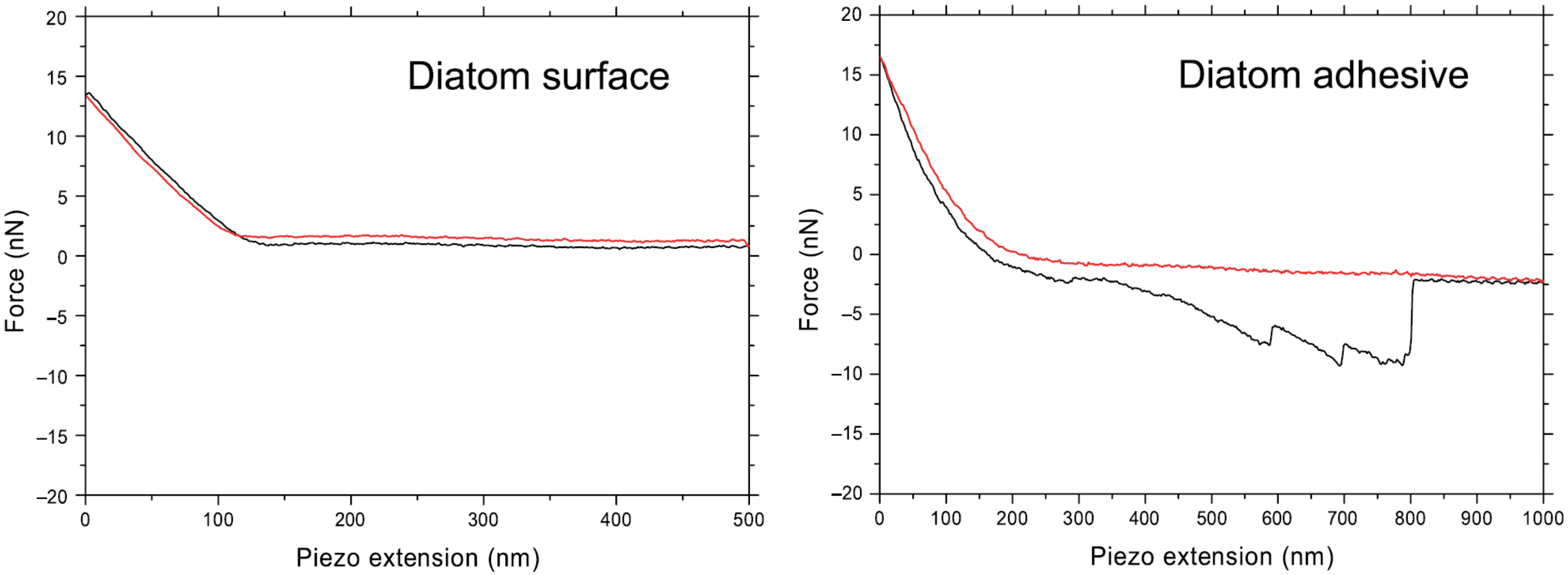
Underwater Adhesives (AFM)



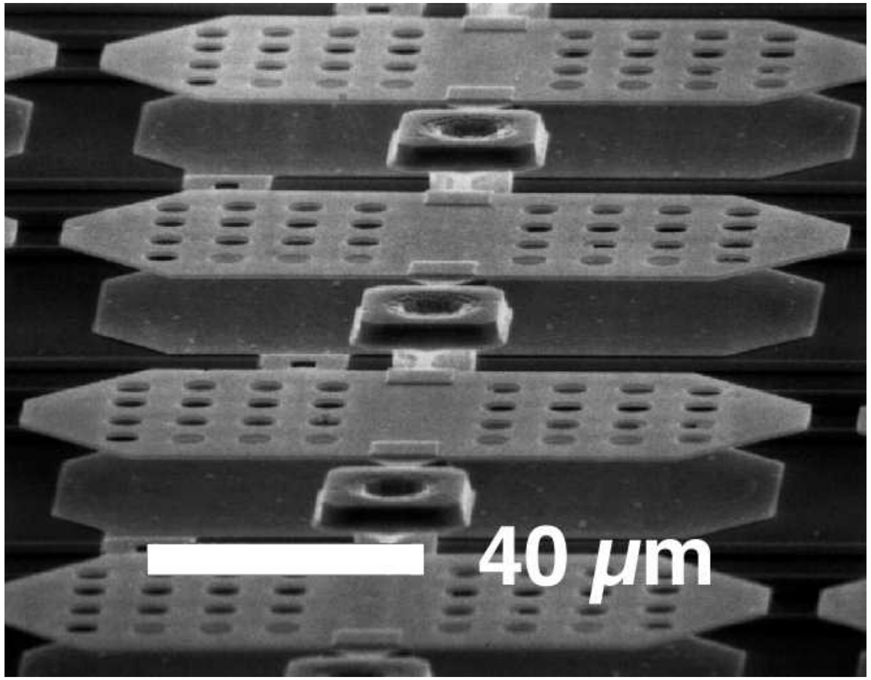
Gebeshuber I.C. *et al.* (2002) *"In vivo nanoscale atomic force microscopy investigation of diatom adhesion properties"*, Mat. Sci. Technol. **18**, pp. 763-766.
Gebeshuber I.C. *et al.* (2003) *"Atomic force microscopy study of living diatoms in ambient conditions"*, J. Microsc. Oxf. **212**, pp. 292-299.

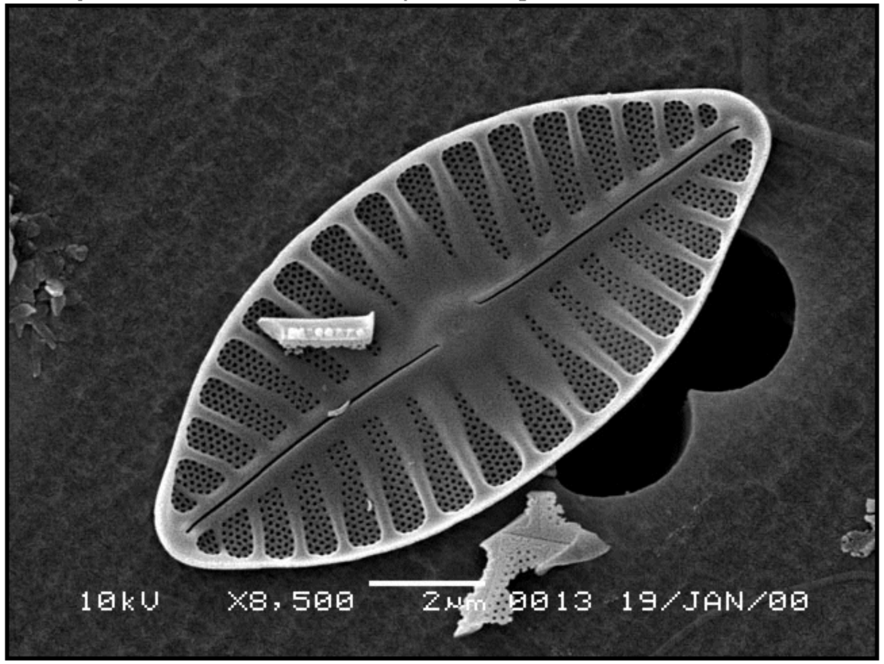
To access the adhesive under the diatom → remove cell with STM tip!

Diatom adhesives



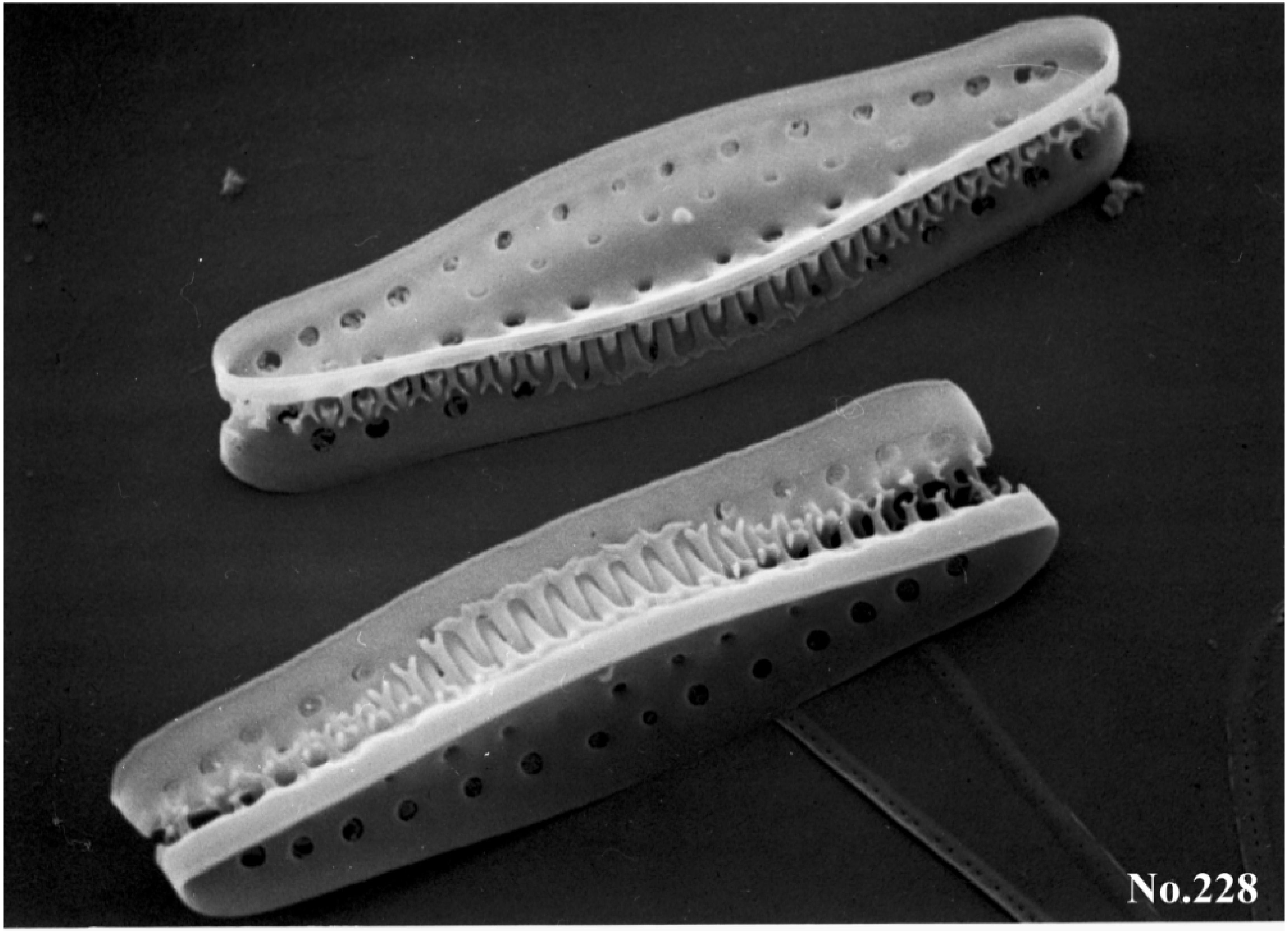
Biotribology



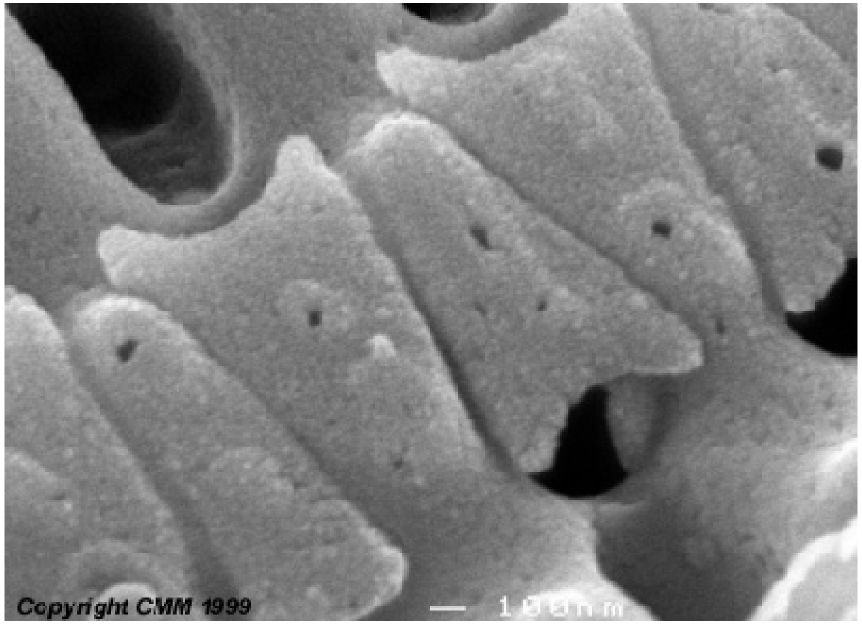


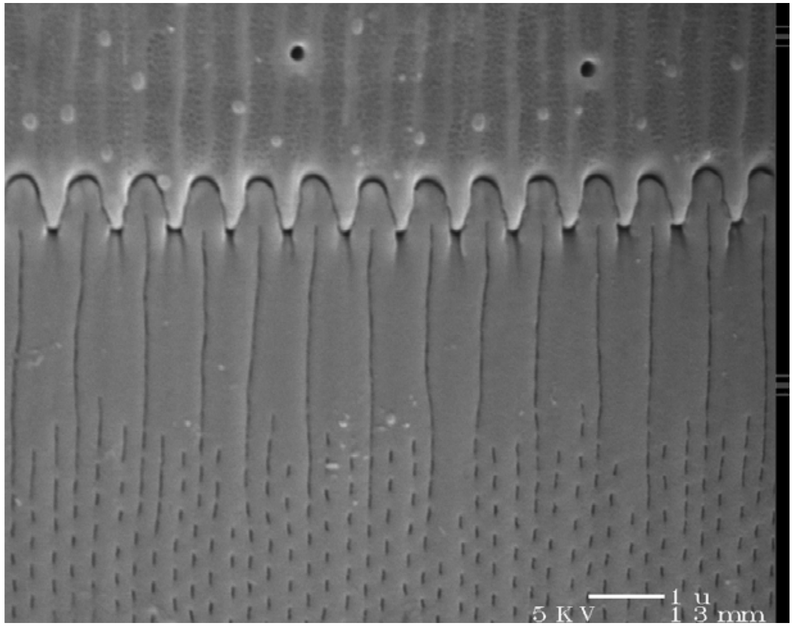
Technical microsystems often experience failure.

Biological micro- and nanomechanical systems are reliable also at this scale.


No.228

Biotribology

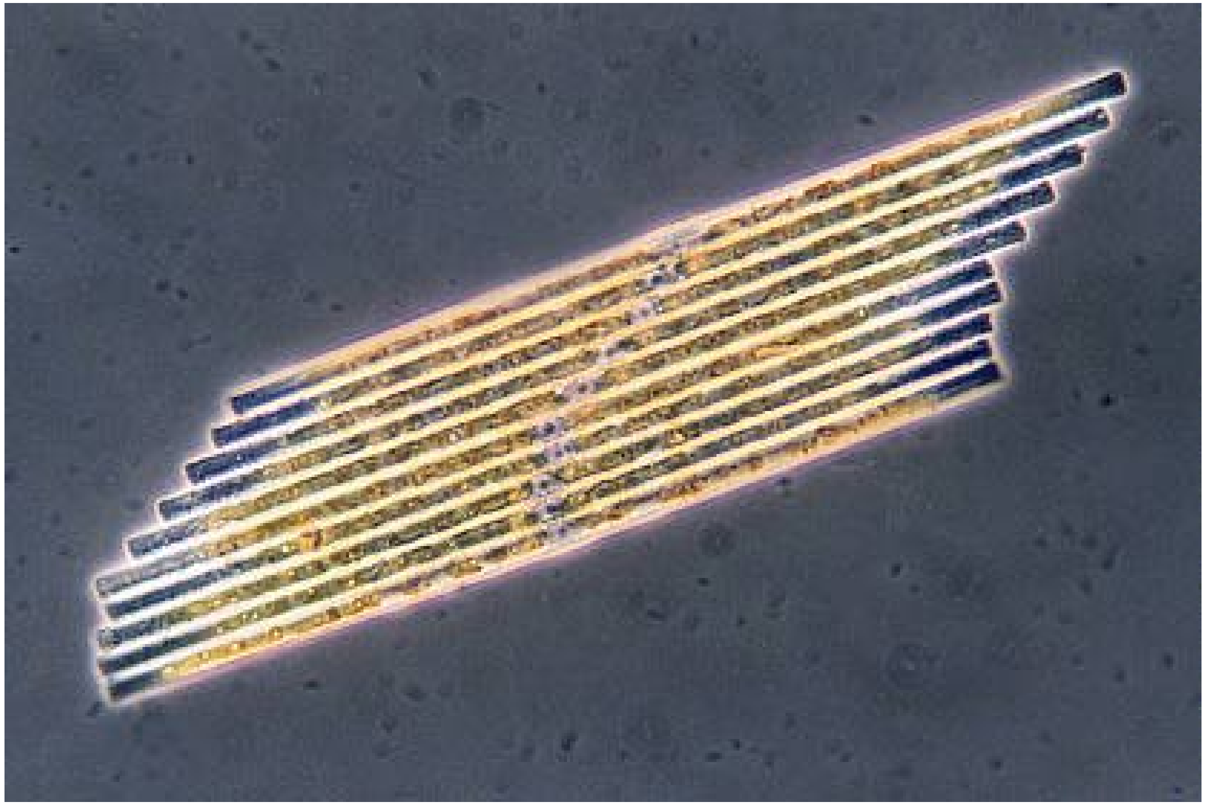




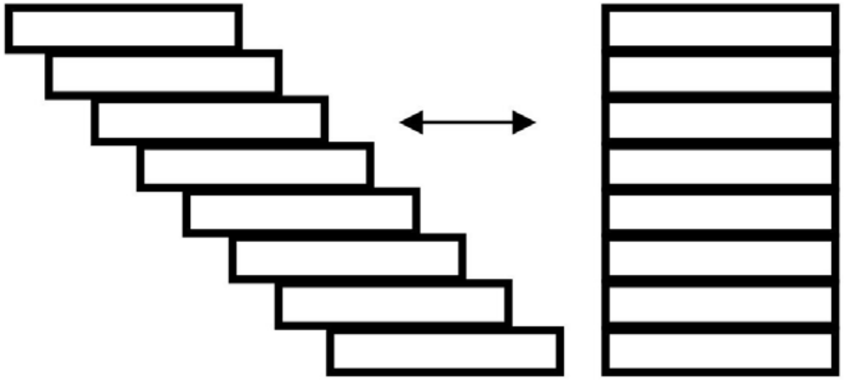
The aim of biotribology is to gather information about **friction, adhesion, lubrication and wear of biological systems** and to **apply** this knowledge **to innovate technology**, with the additional benefit of **environmental soundness**.

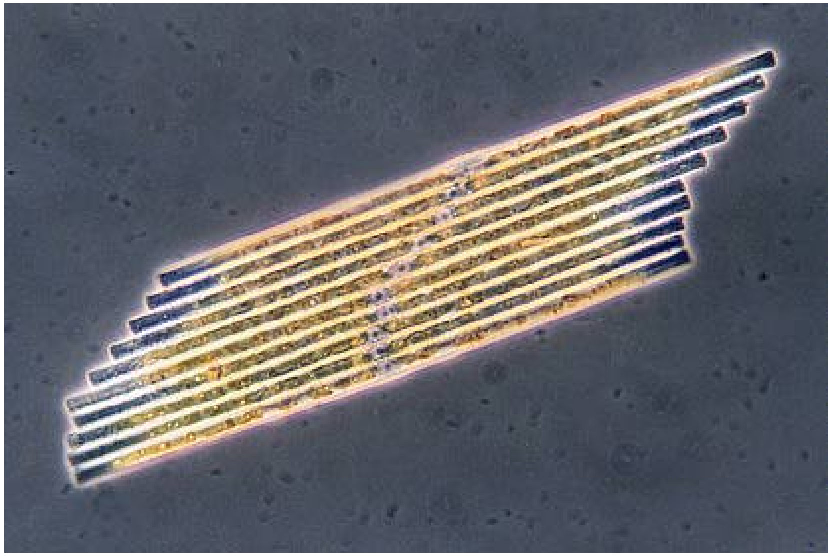
Gebeshuber I.C. *et al.* Nanosci. Nanotechnol. (2004, in press)
Gebeshuber I.C. *et al.*, submitted to Tribology Engineering

Diatom species interesting for biotribology



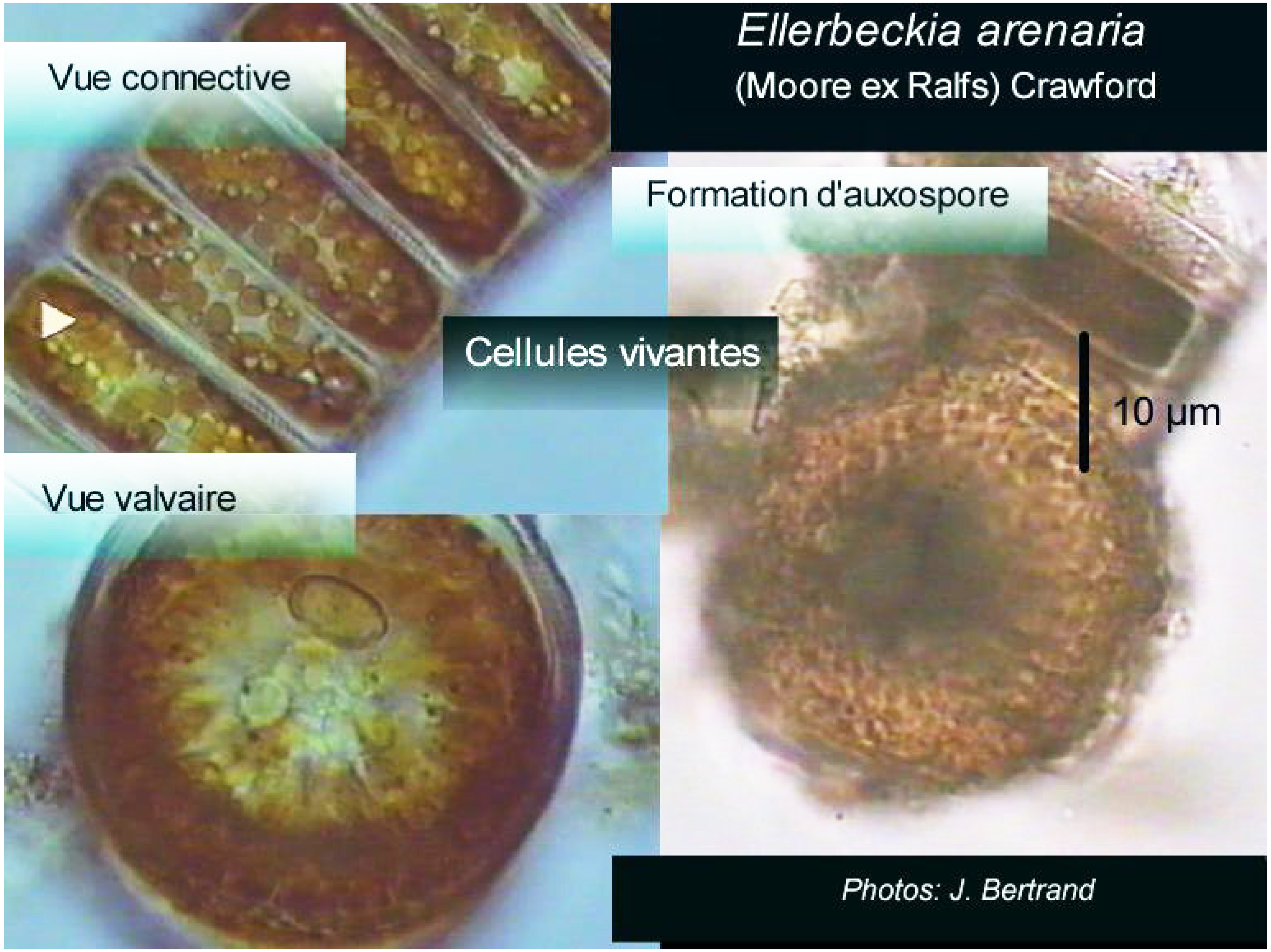
Bacillaria paxillifer (old name: *B. paradoxa*)



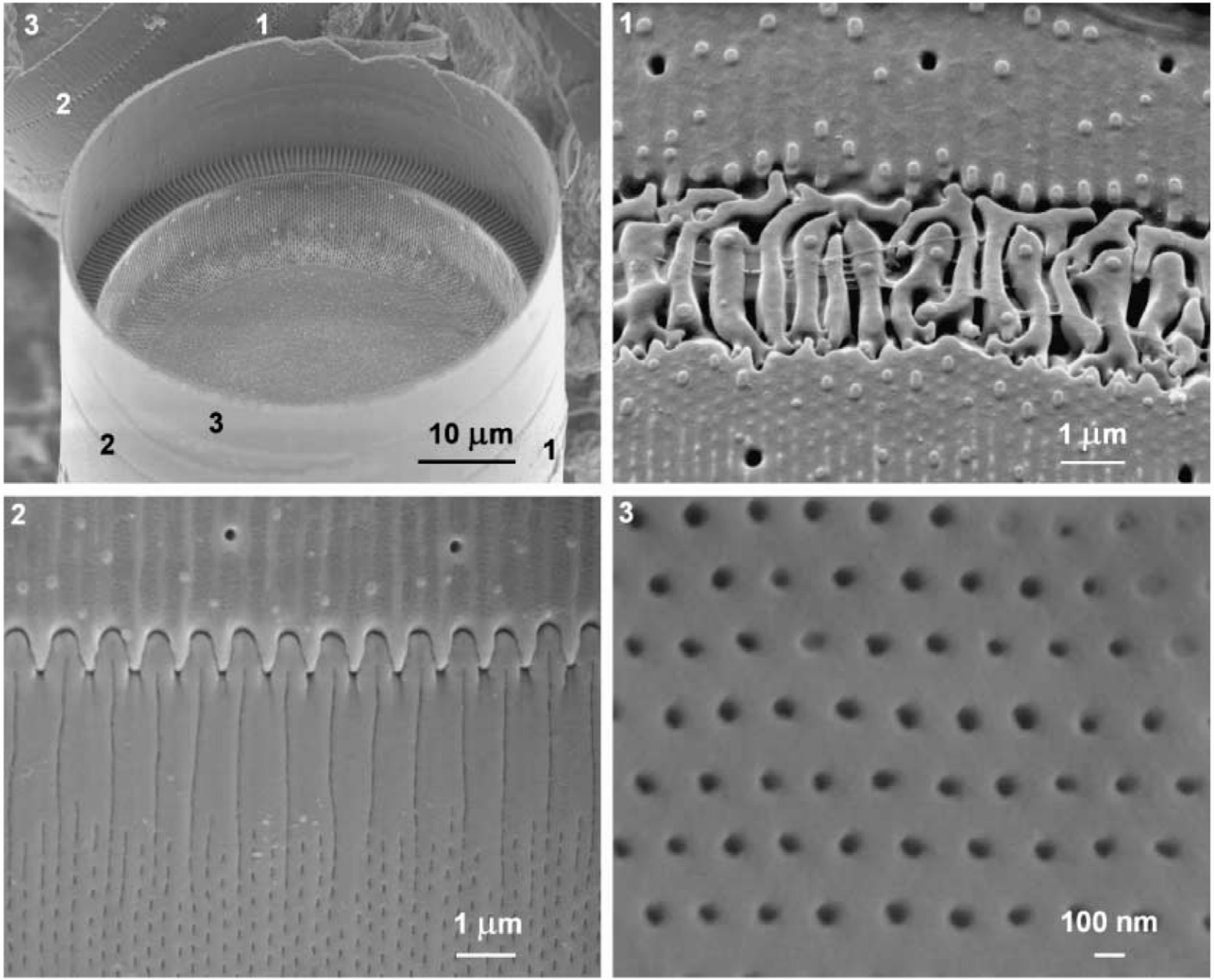


Movie

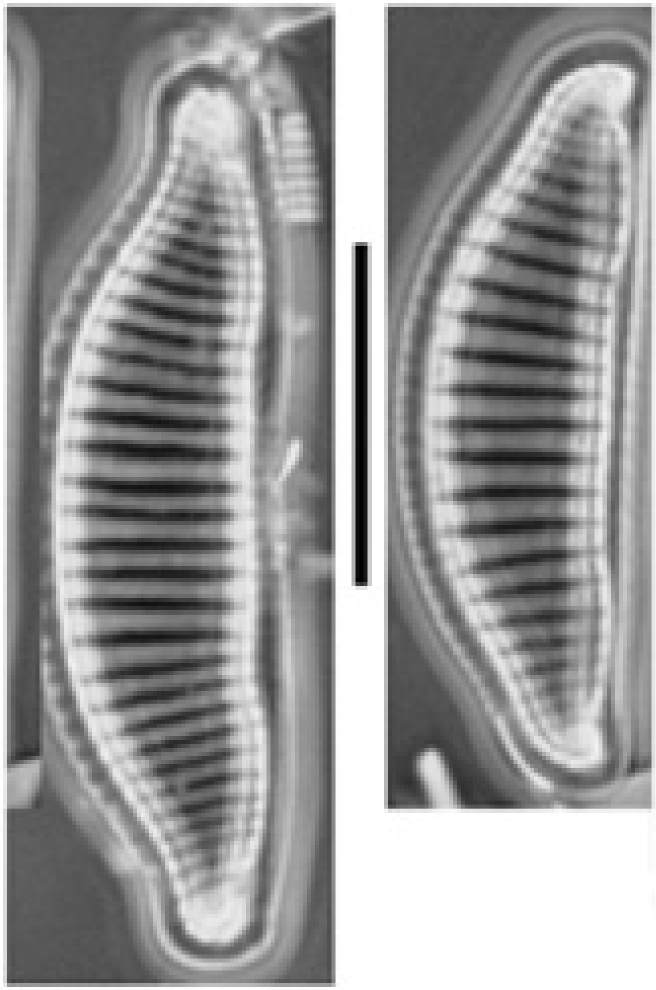
Diatom species interesting for biotribology



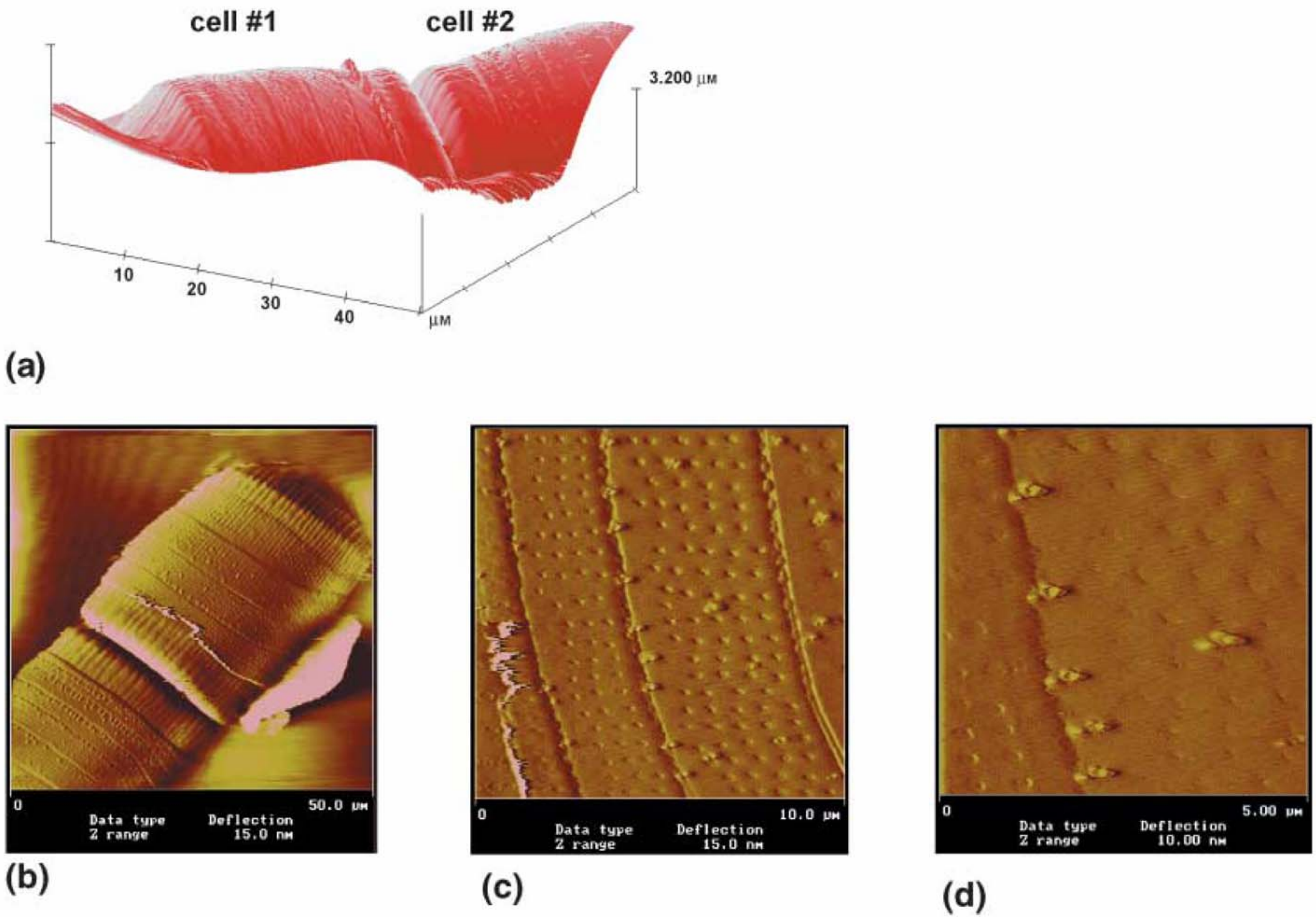
Ellerbeckia arenaria

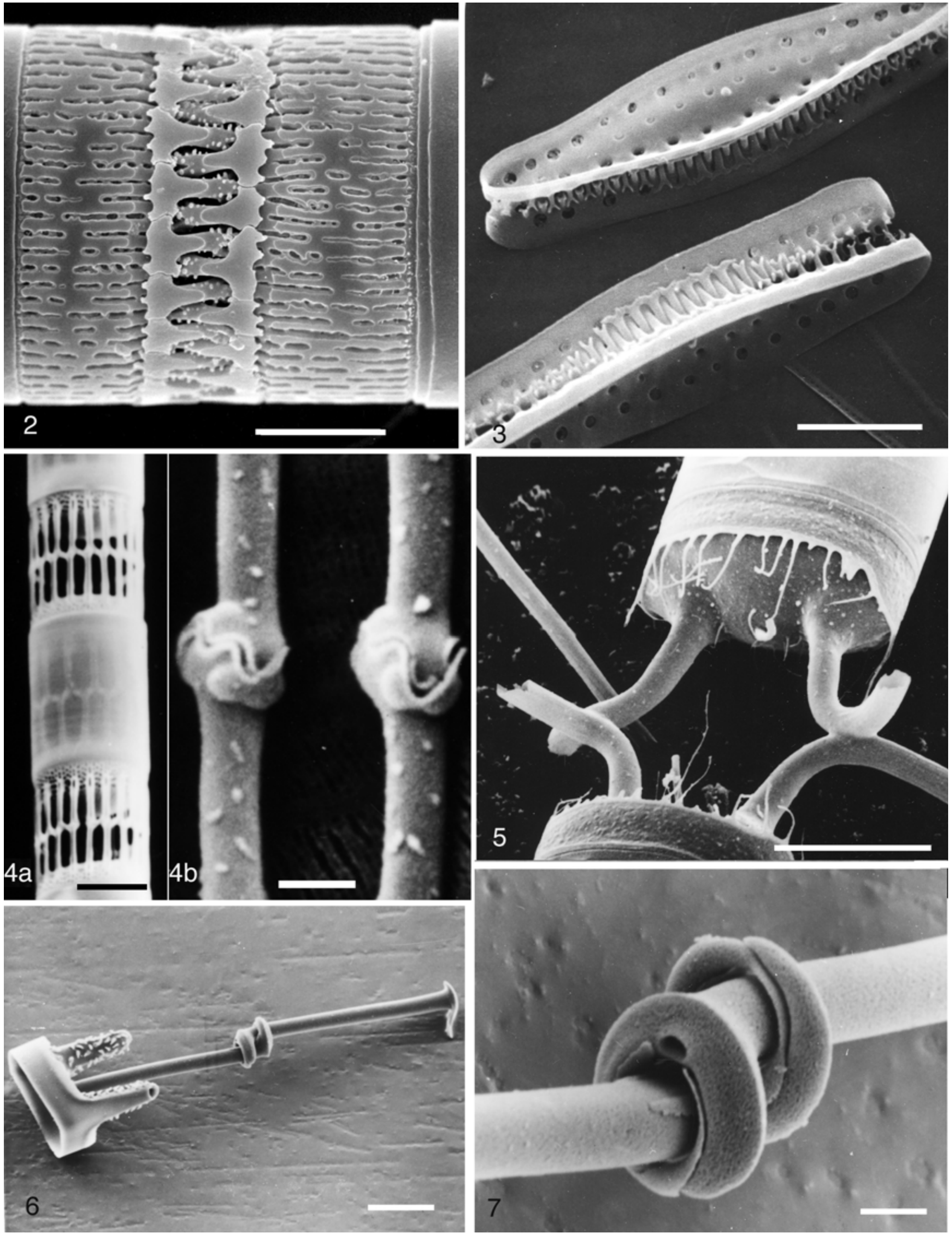

3
1
2
3
2
10 μm
1
1
1 μm
2
1 μm
3
100 nm

Diatom species interesting for biotribology



Eunotia sudetica


cell #1
cell #2
3.200 µm
10
20
30
40
µm
(a)
0
50.0 µm
Data type
Z range
Deflection
15.0 nm
(b)
0
10.0 µm
Data type
Z range
Deflection
15.0 nm
(c)
0
5.00 µm
Data type
Z range
Deflection
10.00 nm
(d)

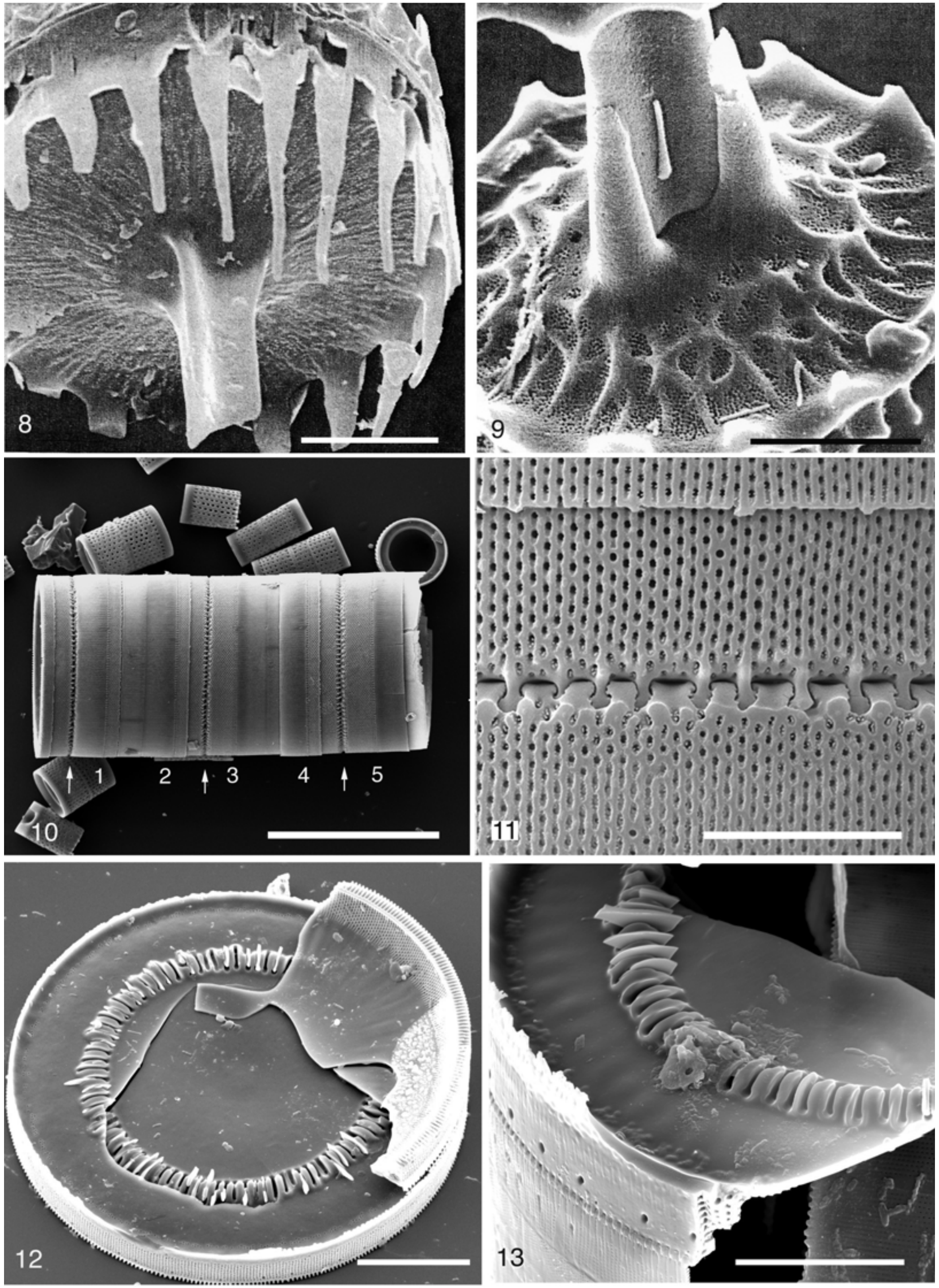


scale bars

5µm,10µm

50µm, 5µm,10µm

20µm,5µm

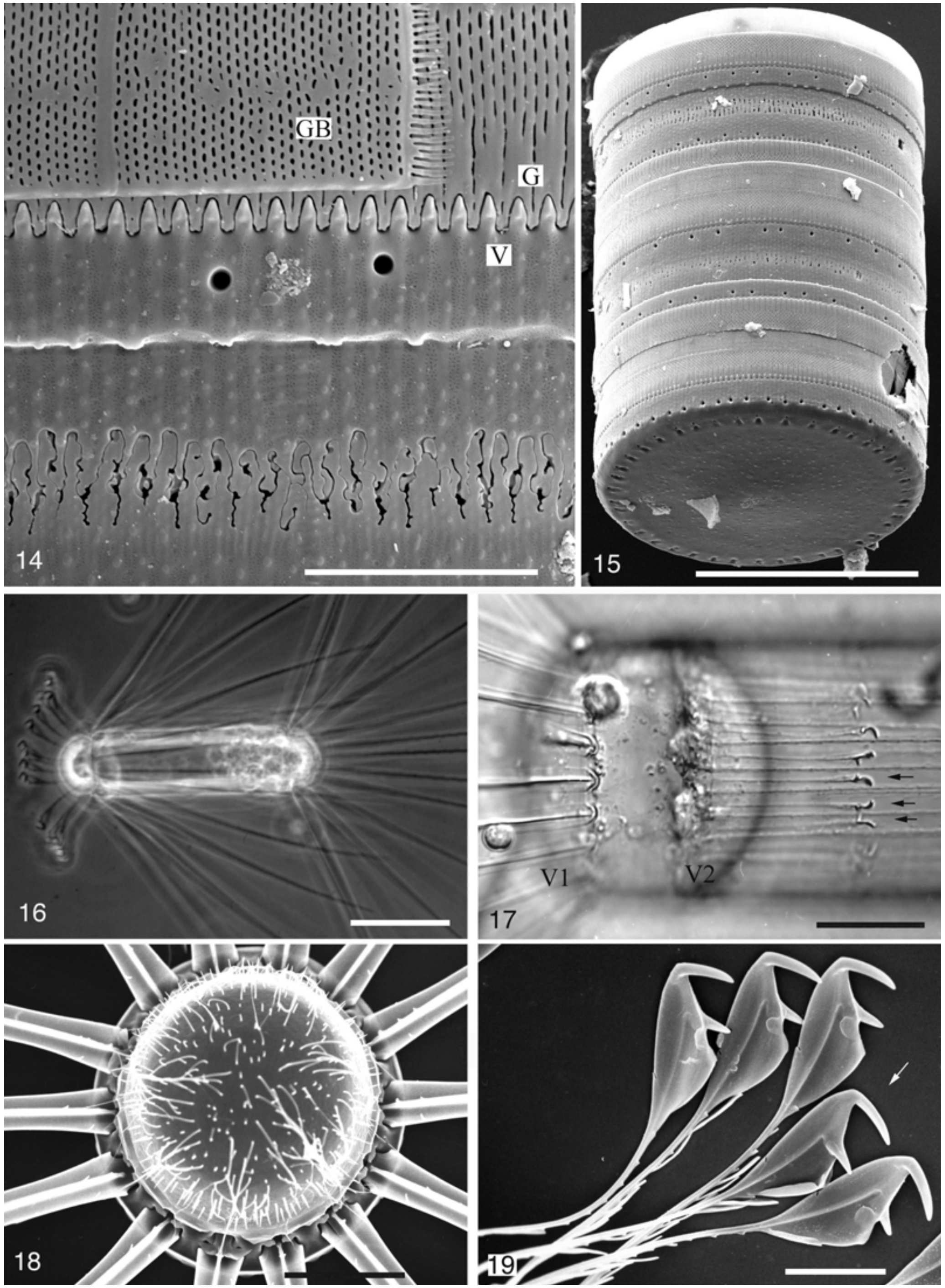


scale bars

50µm,50µm

10µm,5µm

20µm, 5µm



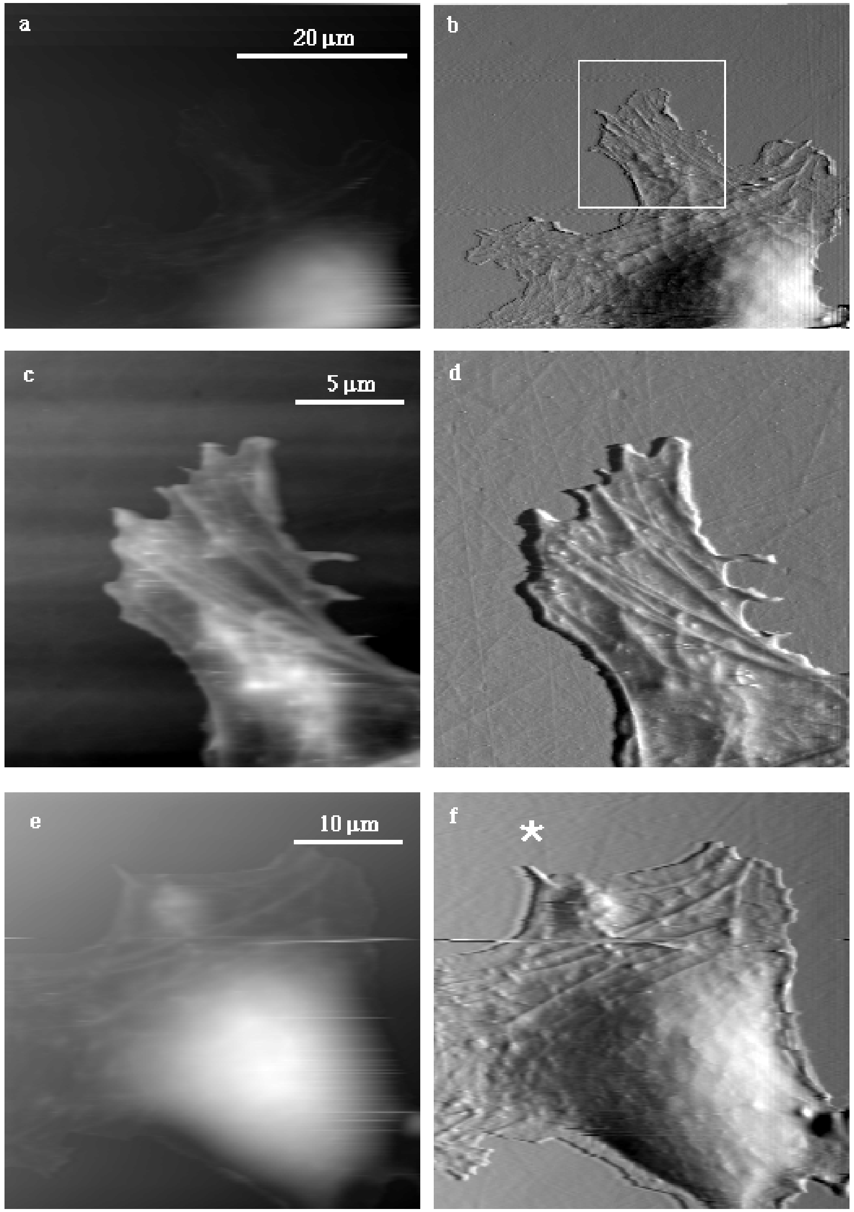
scale bars

5µm,25µm

50µm,20µm

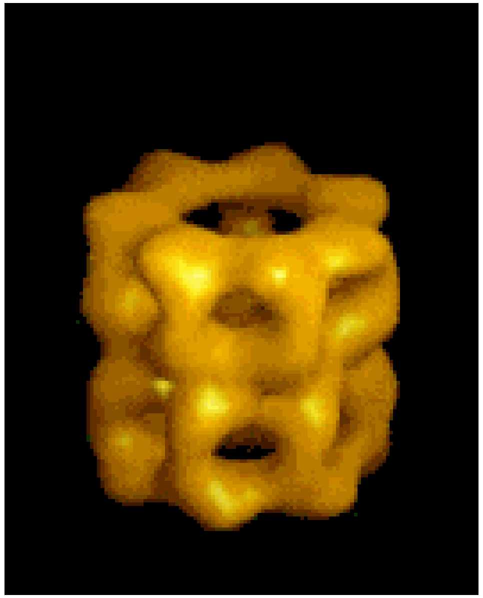
10µm, 10µm

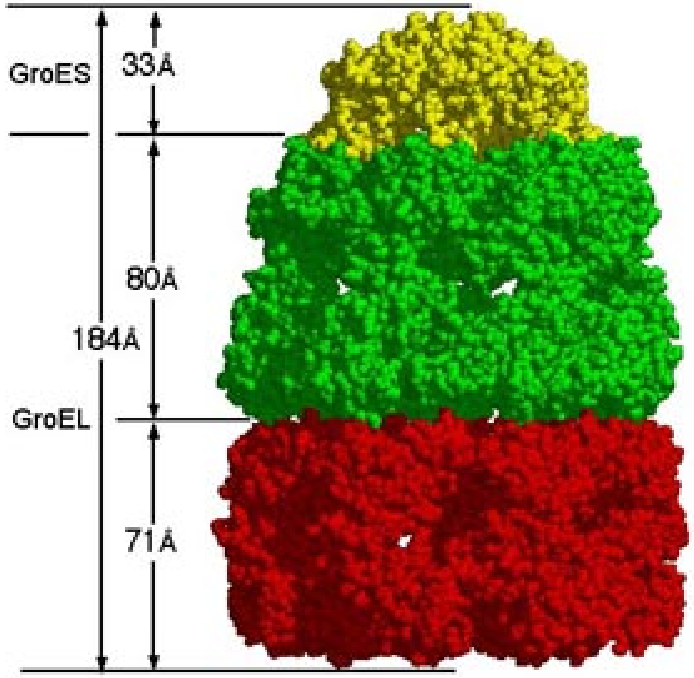
AFM of Living Cells: Fibroblasts



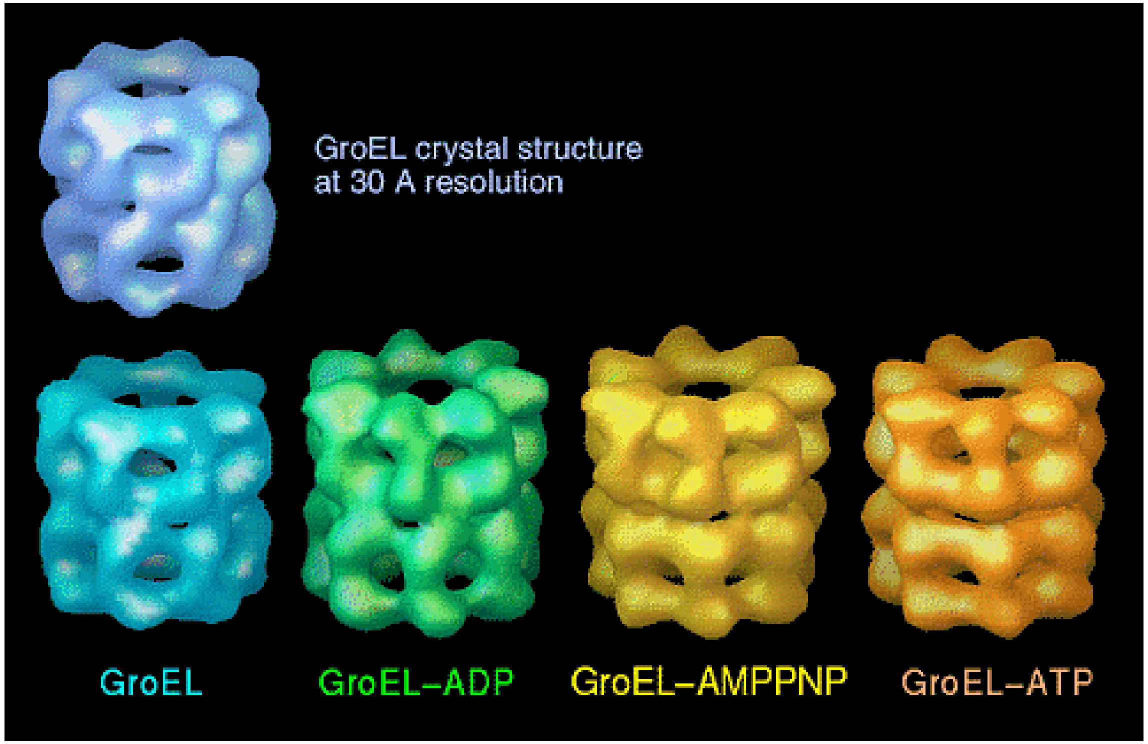
Single Molecules

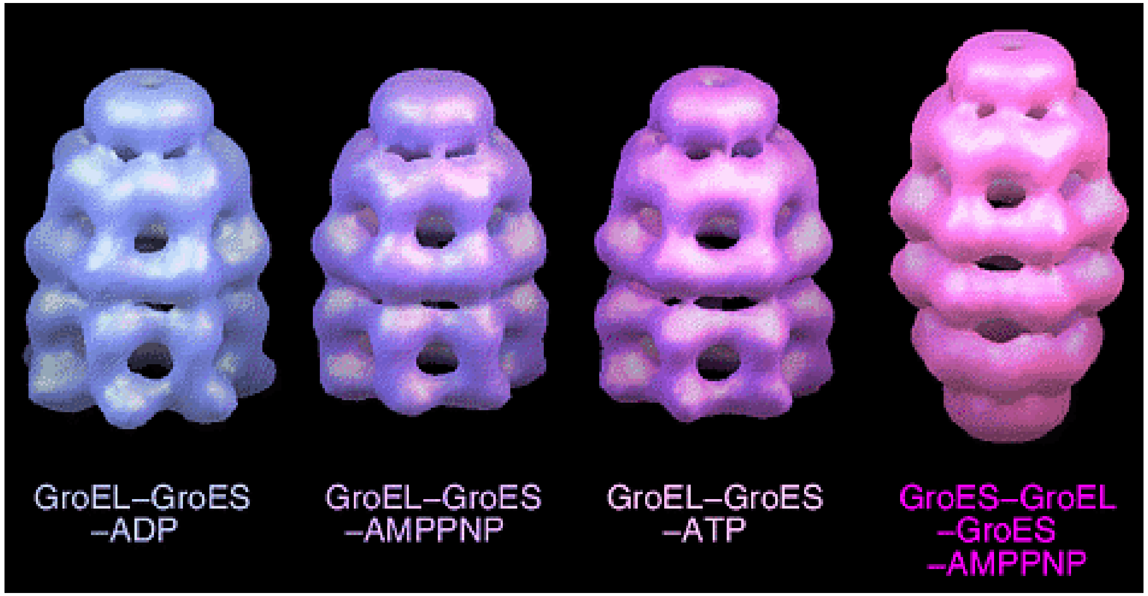
Chaperonins GroEL-GroES



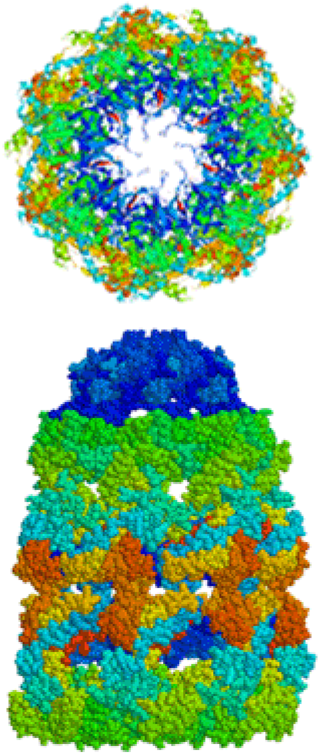


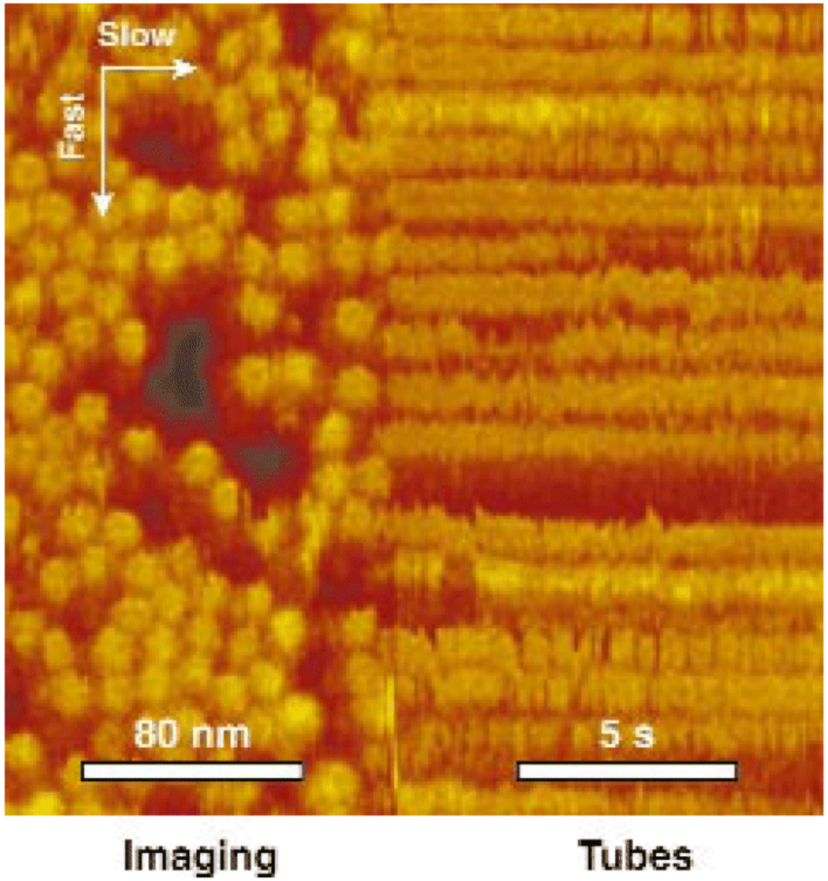
Chaperonins are proteins involved in making certain that other proteins form properly.


GroEL crystal structure
at 30 A resolution
GroEL
GroEL–ADP
GroEL–AMPPNP
GroEL–ATP


GroEL–GroES
–ADP
GroEL–GroES
–AMPPNP
GroEL–GroES
–ATP
GroES–GroEL
–GroES
–AMPPNP

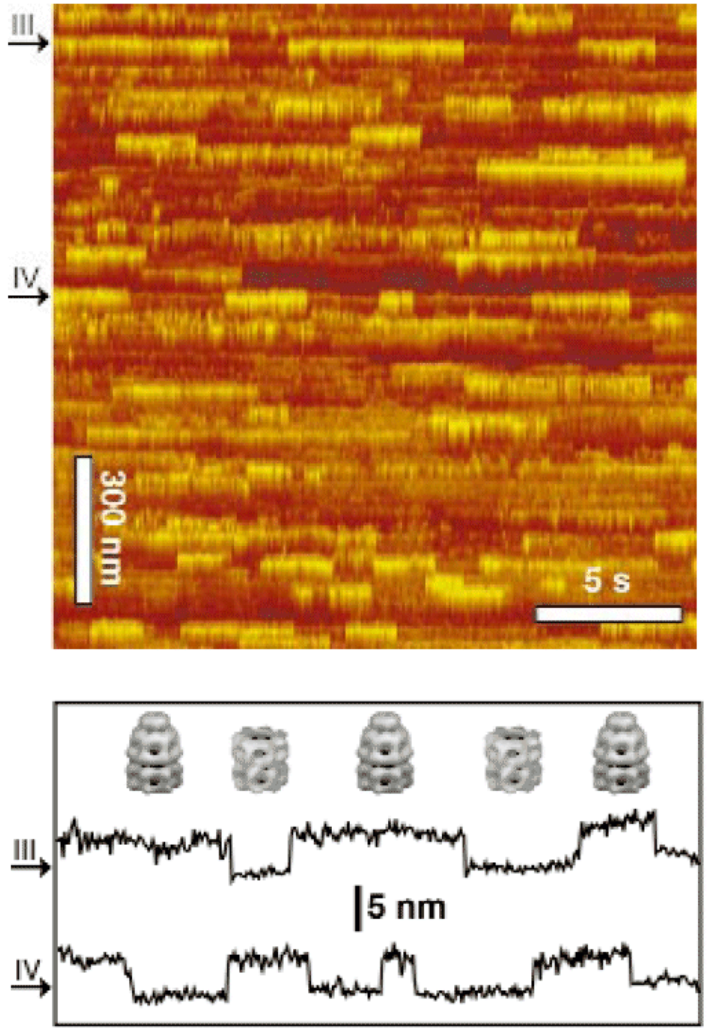
Watching protein-protein interactions in real time

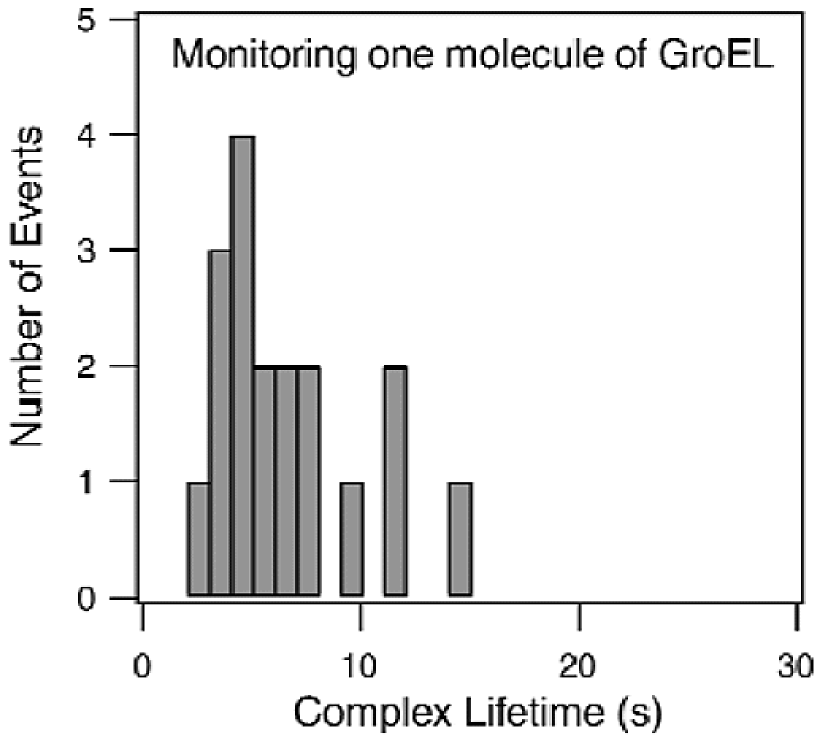




Viani M.B. *et al.* (2000) Nature Struct. Biol. 7, pp. 644-647

Watching protein-protein interactions in real time



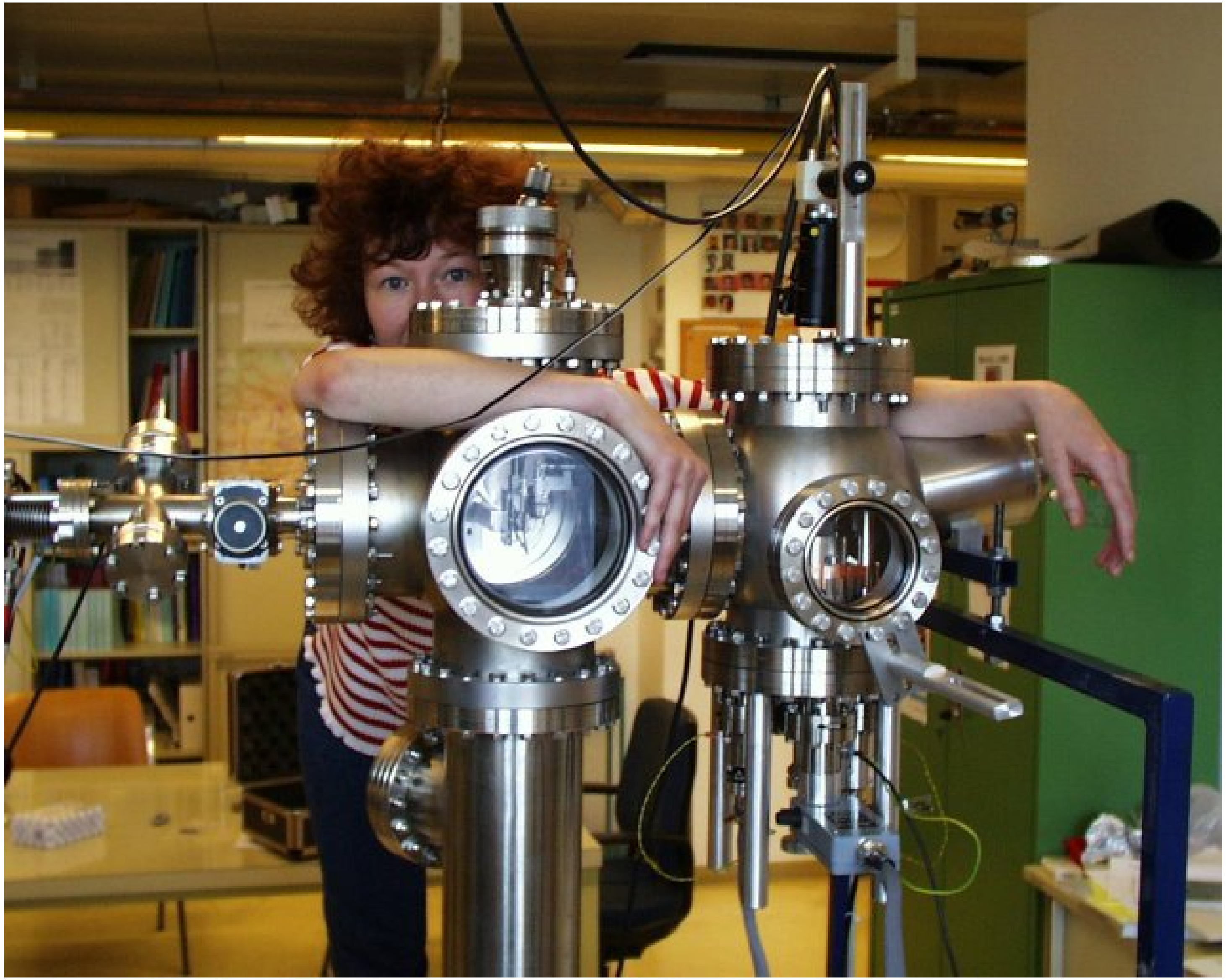


Viani M.B. *et al.* (2000) Nature Struct. Biol. 7, pp. 644-647

Atoms

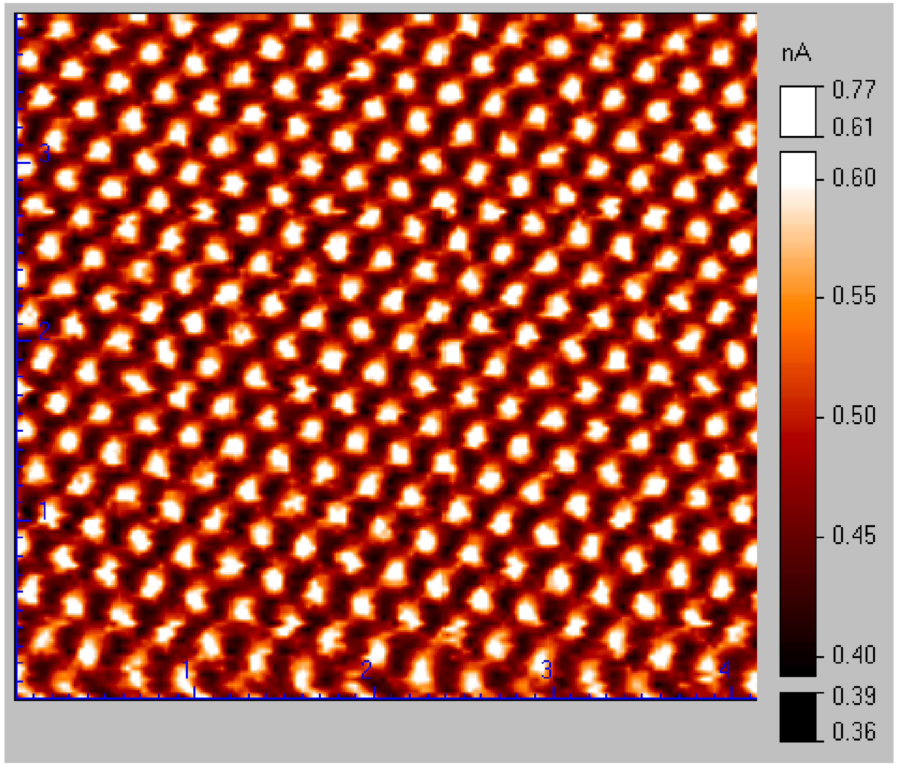
Nanostructuring atomically flat surfaces with ions

Omicron UHV AFM/STM



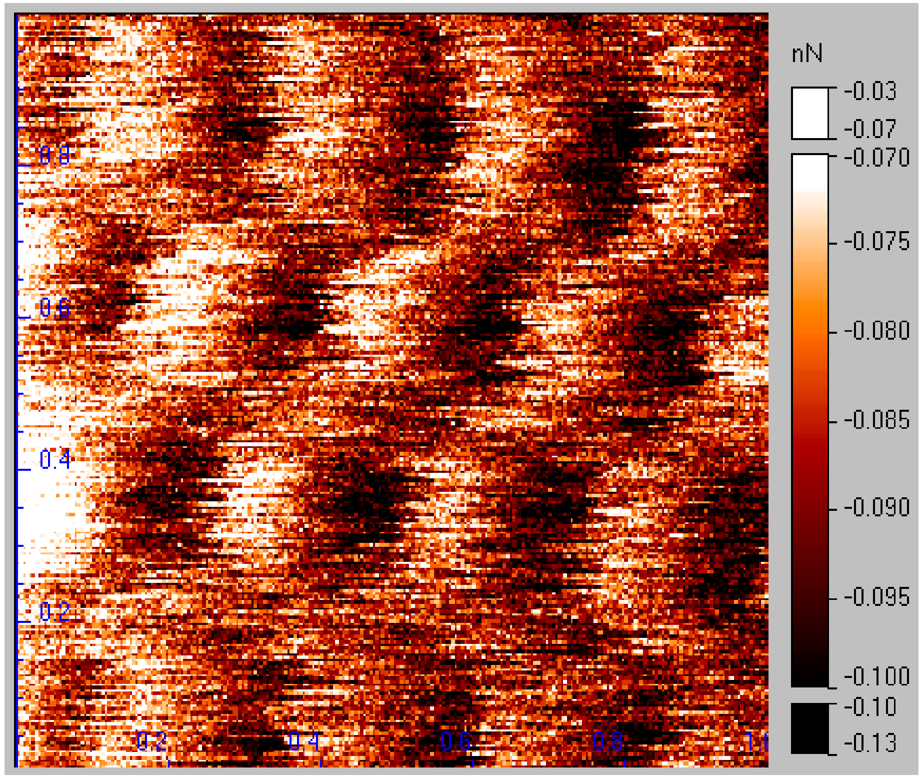
Atomically flat HOPG crystals before ion bombardement

STM



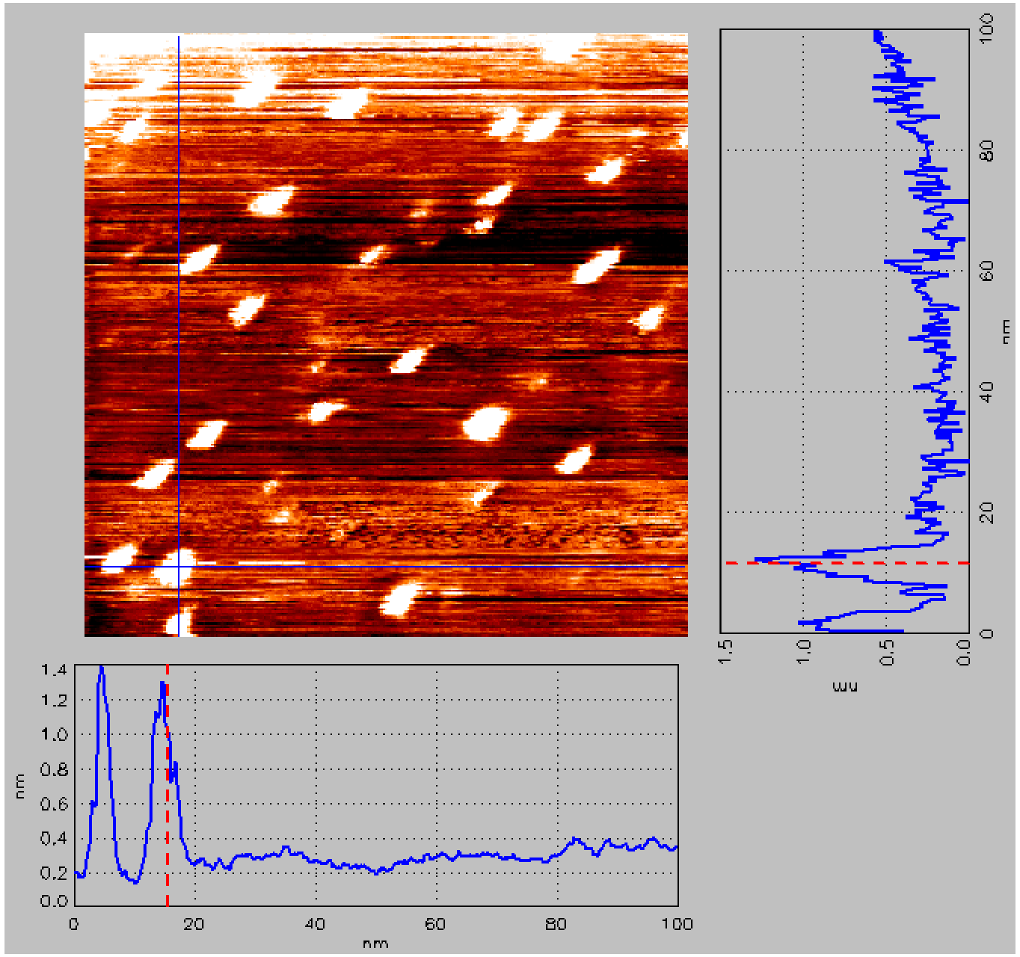
HOPG, 4*4 nm^2

AFM



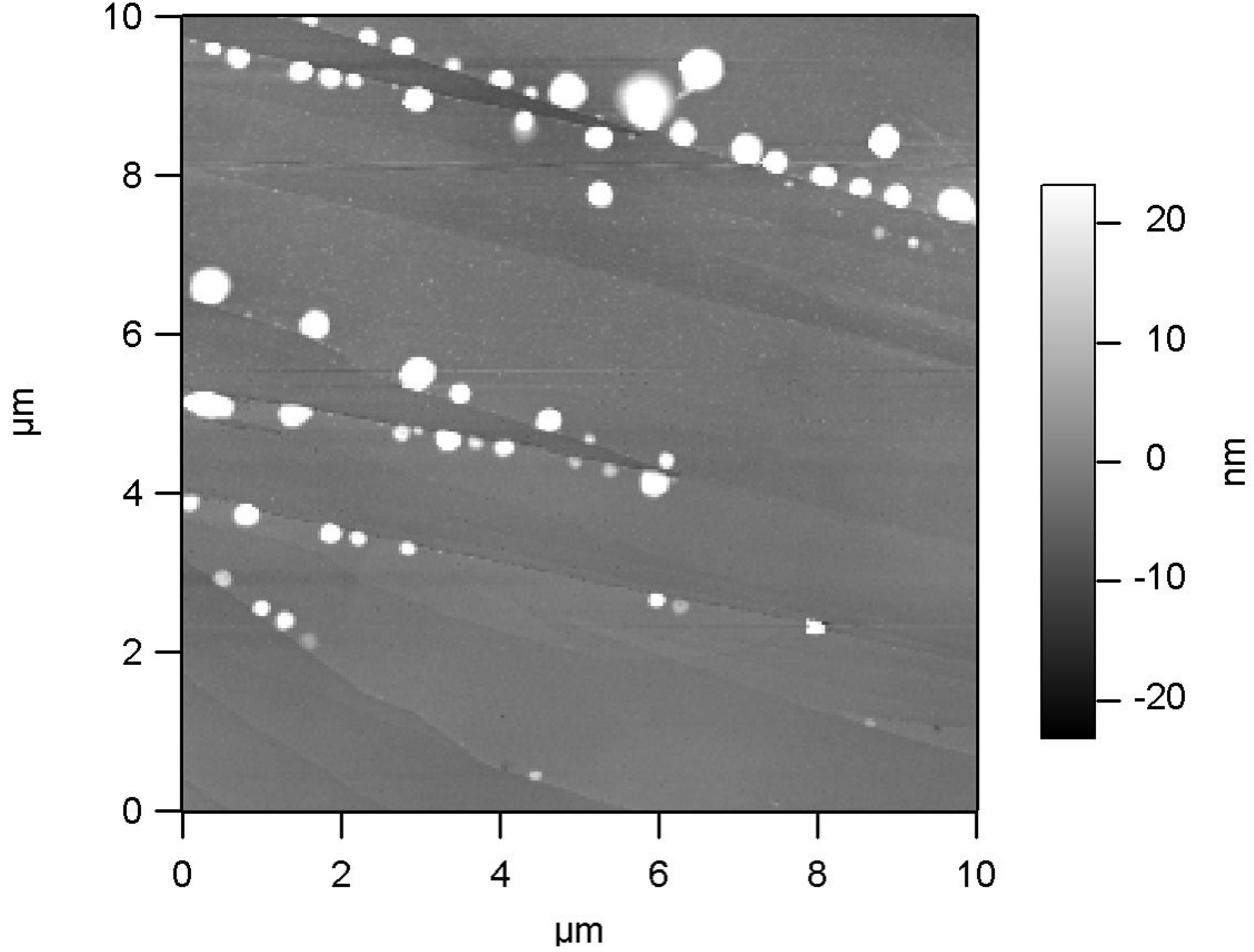
HOPG, 1*1 nm^2

HOPG after ion bombardment

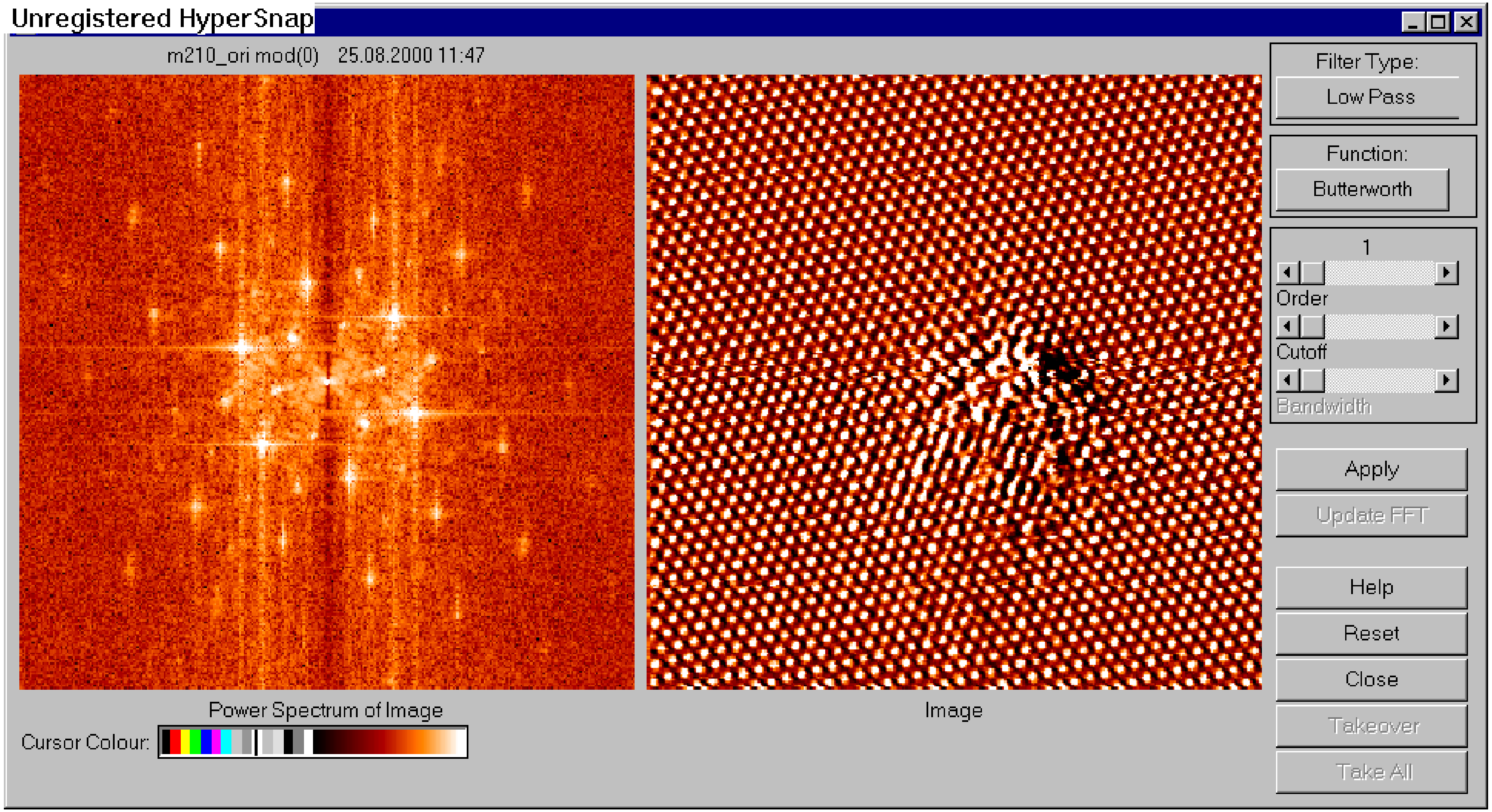


STM, 100·100nm², HOPG bombarded with 800 eV Ar^+ ions

Nanodefect aggregation on HOPG steps



HOPG after ion bombardment

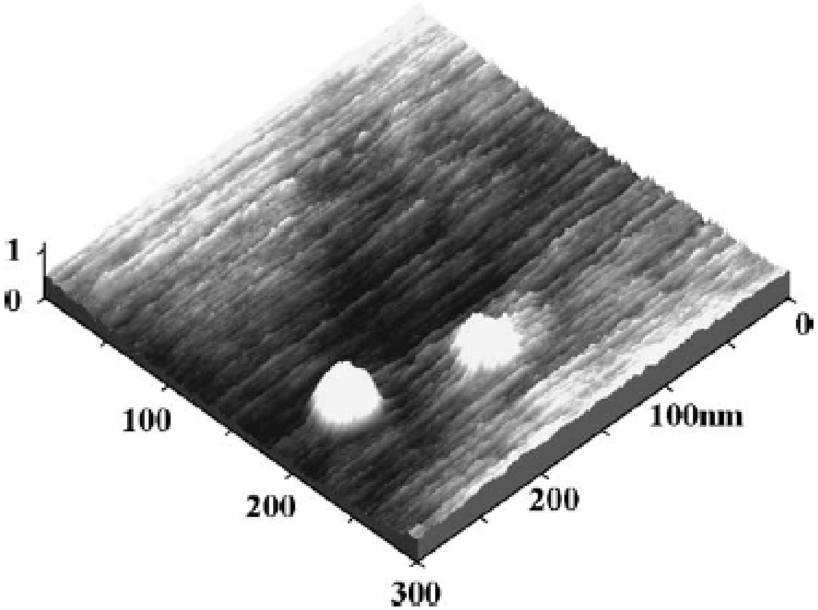


STM, 10·10nm^2, HOPG bombarded with 800 eV Ar^+ ions

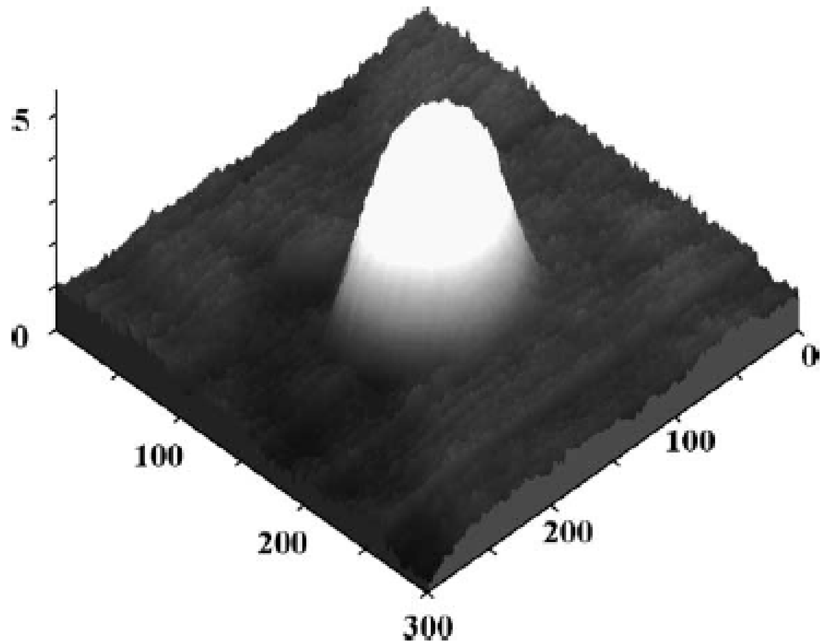
Gebeshuber I.C. *et al.* (2003) Nucl. Instrum. Meth.
Gebeshuber I.C. *et al.* (2003) Int. J. Mass. Spectrosc.

Ion bombardment of atomically flat insulator crystals

Potential Sputtering



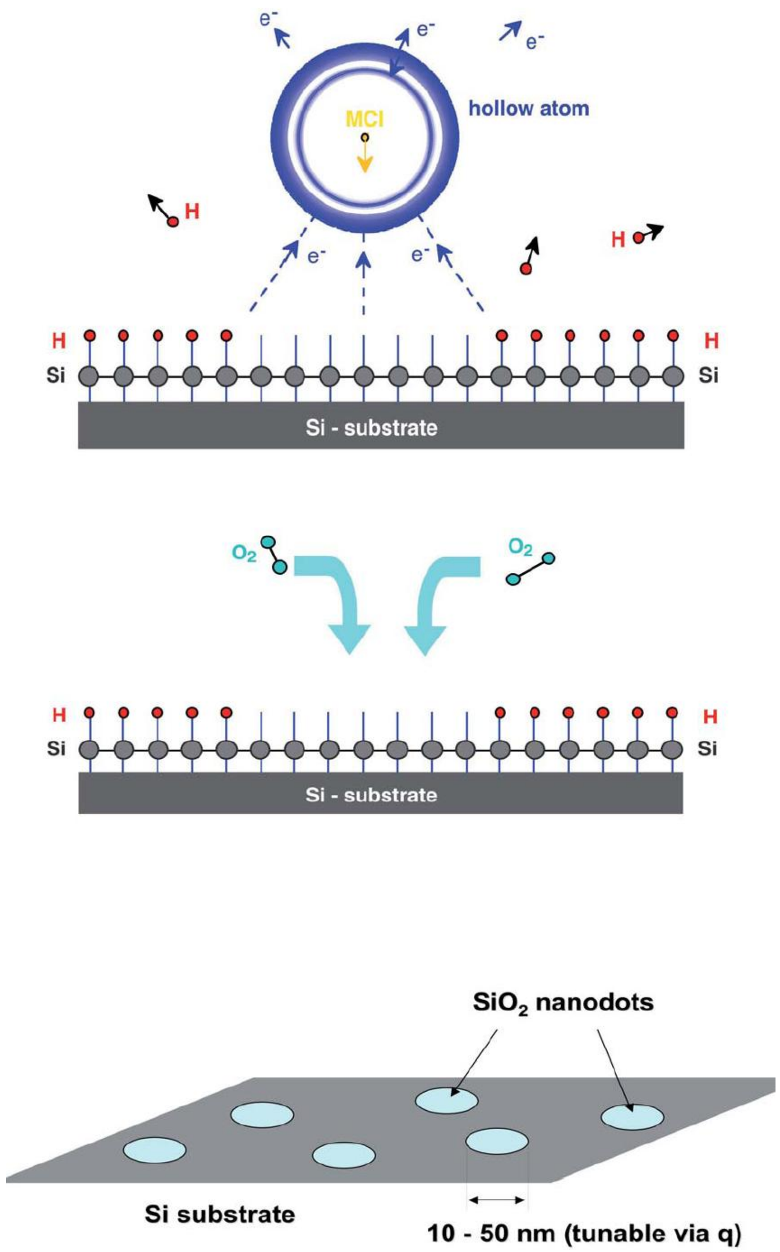
500 eV Ar^{+}



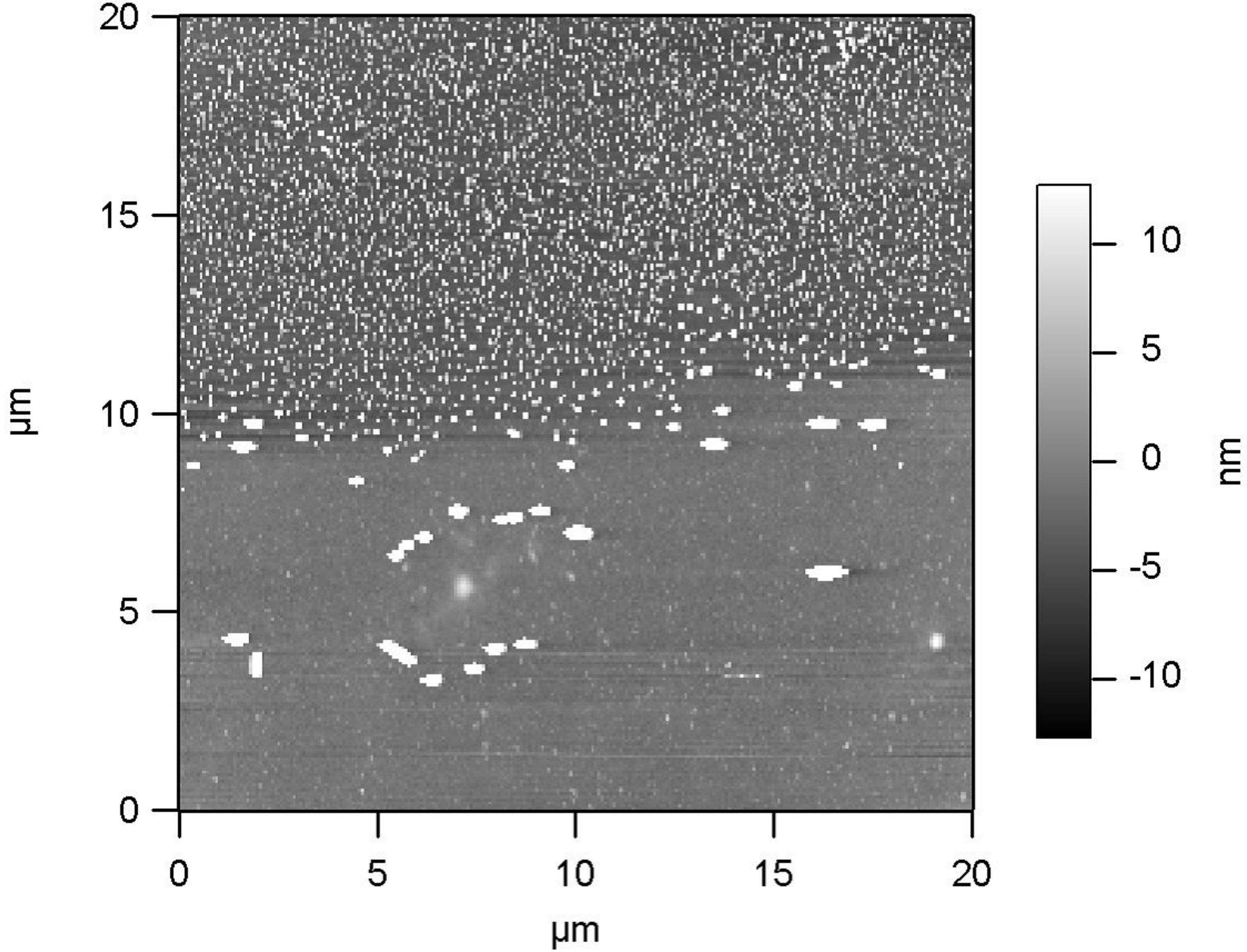
500 eV Ar^{7+}

UHV AFM contact mode image of sapphire (Al_2O_3, c-plane 0001) bombarded with ions with the same kinetic, but different potential energy.

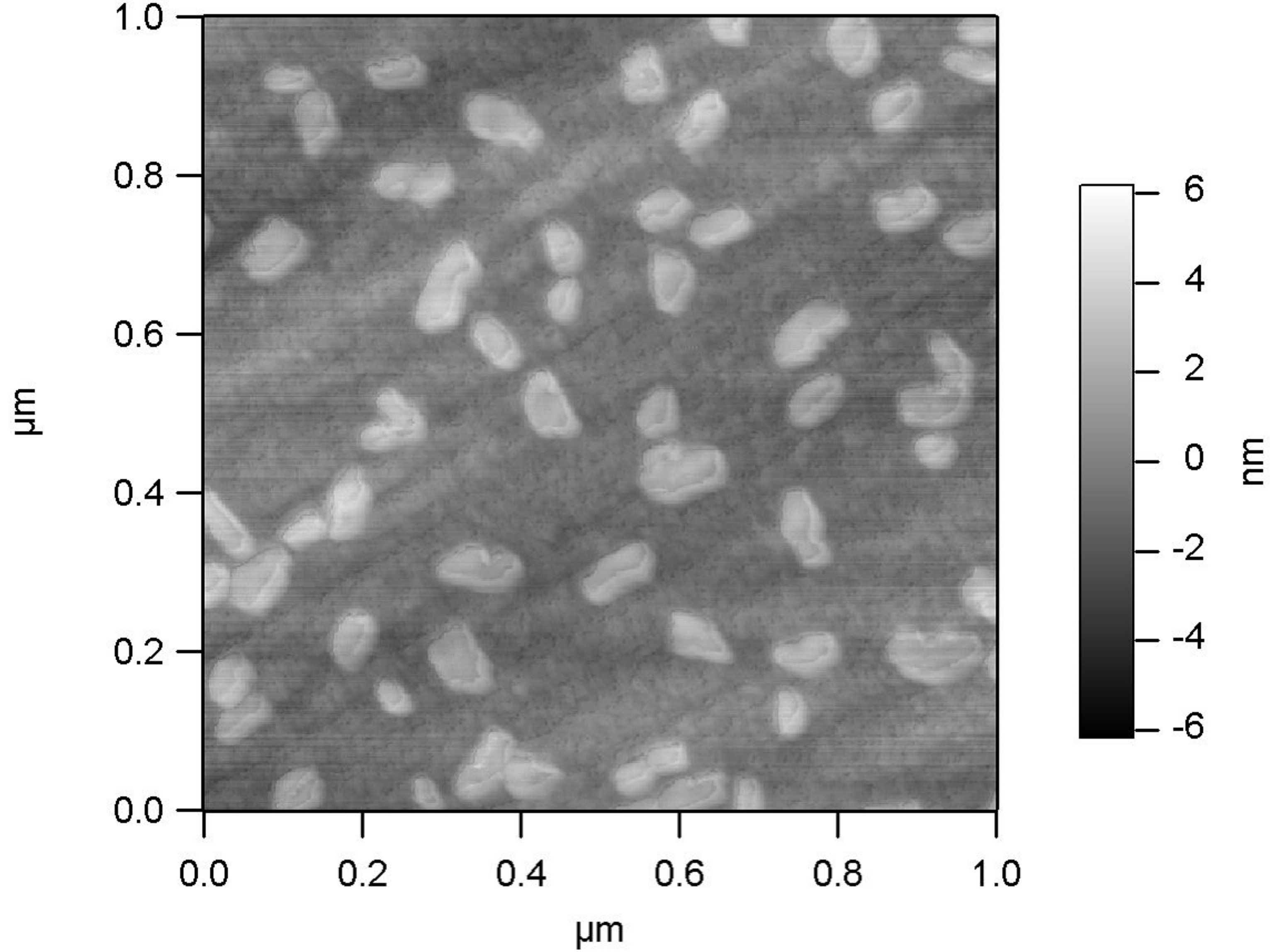
Nanodot formation on Silicon



Nanodot formation on Silicon

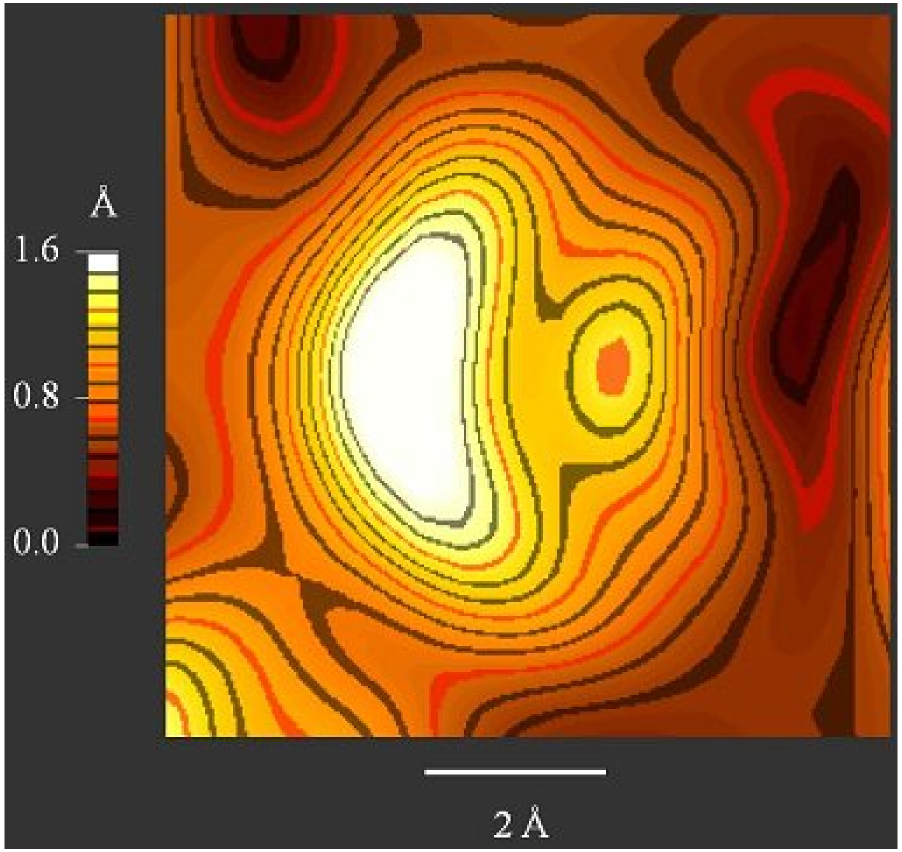


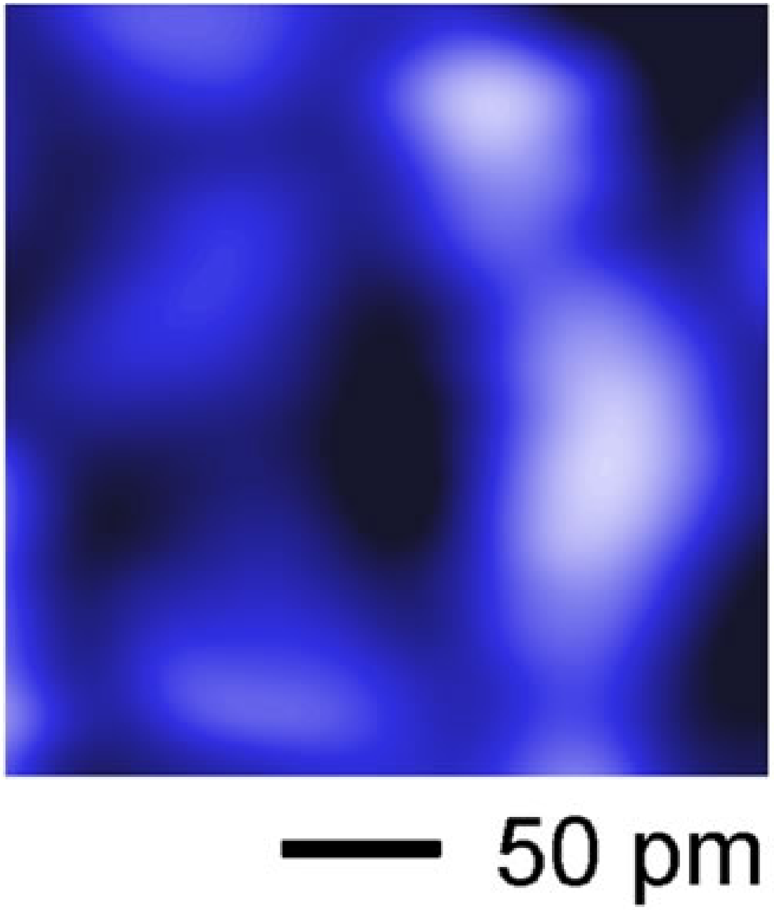
Ion induced nanodefects on LiF



Subatomic features

Atom orbitals (AFM)

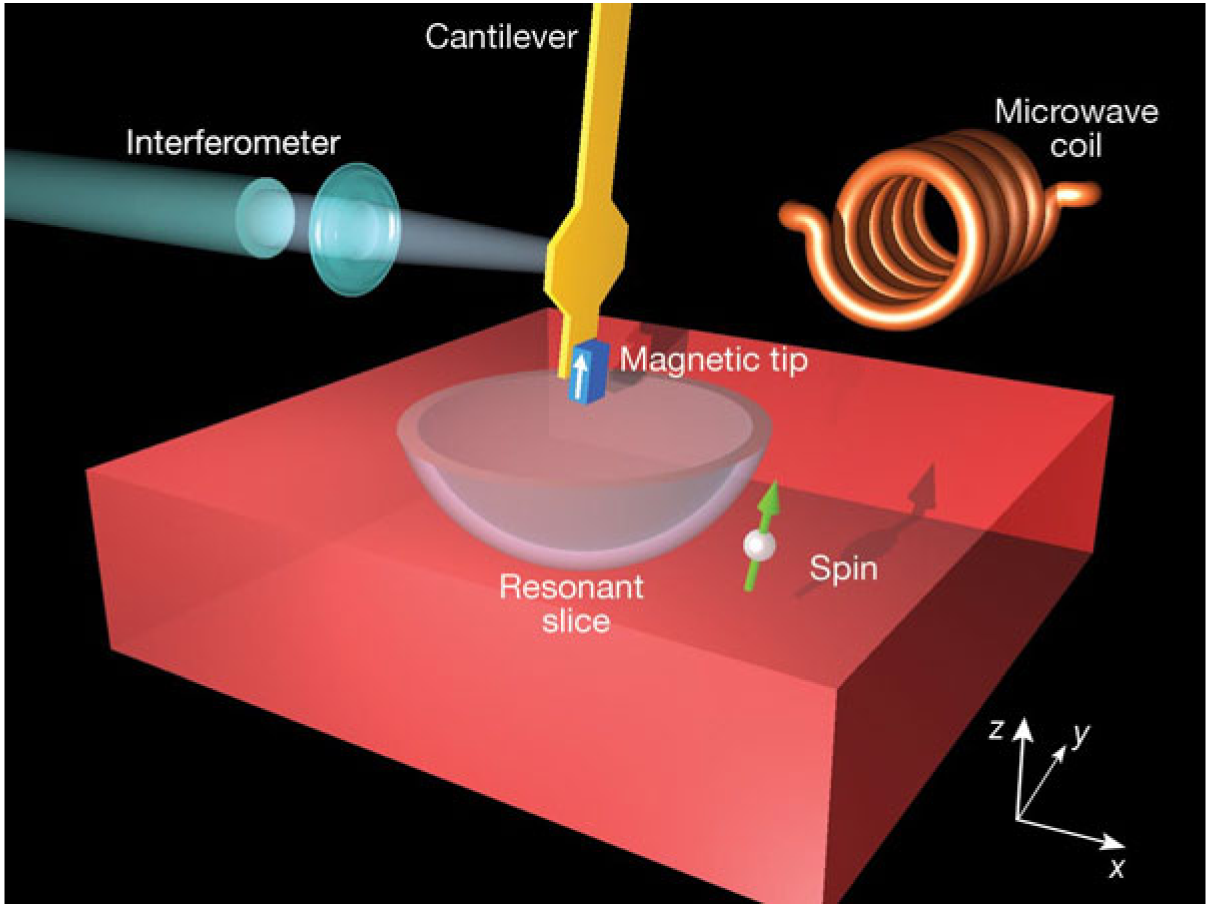




F.J. Giessibl, S. Hembacher, H. Bielefeldt and J. Mannhart (2000) *Subatomic features on the Silicon (111)-(7*7) surface observed by atomic force microscopy.* Science 289, pp. 422-425.

S. Hembacher, F.J. Giessibl and J. Mannhart (2004) *Force Microscopy with Light-Atom Probes.* Science 305, pp. 380-383.

Seeing single spins (AFM)

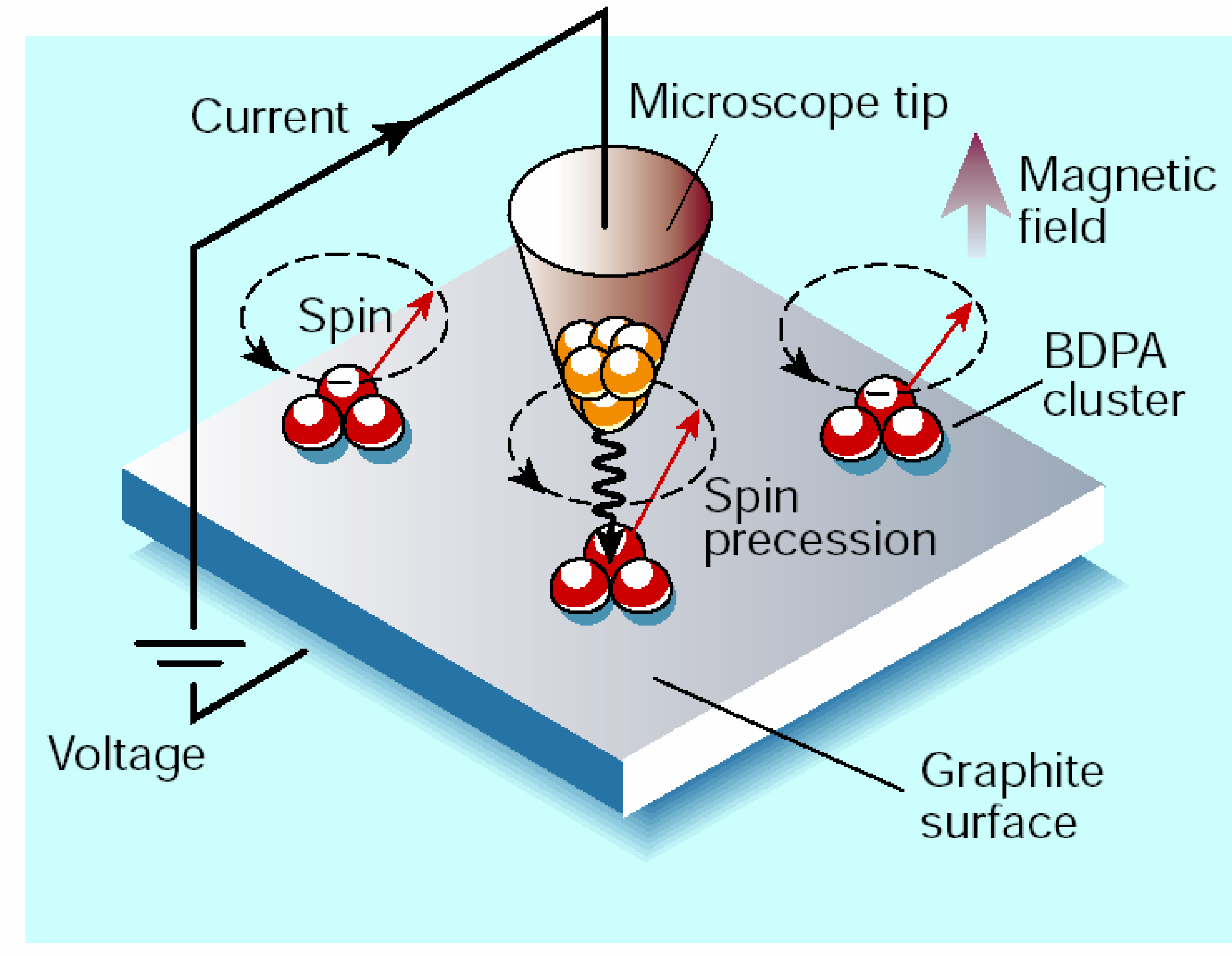


D. Rugar, R. Budakian, H. J. Mamin and B.W. Chui (2004)
Single spin detection by magnetic resonance force microscopy
Nature 430, pp. 329-332.

3D microscope with atomic resolution

- Developed further, the MFRM technique could prove useful for investigating the atomic structure inside materials used in the electronics industry and to image biomolecules - like proteins - at atomic resolution.
- However, to reach this goal, nuclear spins have to be detected.
- Nuclear spins are harder to detect than electron spins, because a proton´s magnetic moment is 658 times weaker than an electron's.

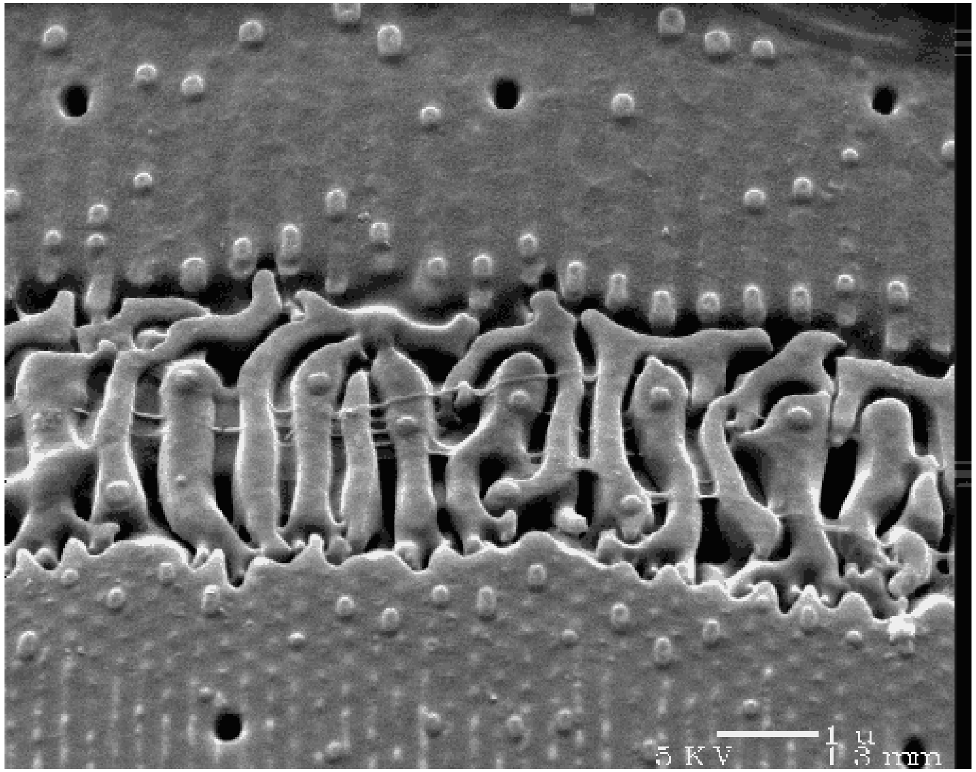
Seeing single spins (STM)



H.C. Manoharan (2002), *Spin spotting*, Nature 416, pp. 24-25 (Nature News&Views on C. Durkan and M. Welland (2002), Electronic spin detection in molecules using scanning-tunneling-microscopy-assisted electron-spin resonance, Appl. Phys. Lett. 80, 458-460, an article which is reproducing (with different sample) Y. Manassen et al. (1989), *Direct observation of the precession f individual paramagnetic spins on oxidezed silicon surfaces*. Phys. Rev. Lett. 62(21), 2531-2534)

ॐ भूर्भुवः स्वः
तत्सतिुर्वरेण्यं ।
भर्गो देवस्य धीमहि
धियो यो नः प्रचोदयात् ।।

Gayatri mantra,
written in Sanskrit



Ellerbeckia arenaria,
the rubberband diatom

Thank you for your attention !

Nanotechnology

Outlook

30.11.2005: Practical demonstrations at our institute

07.12.2005: Clemens Grünberger and **Dipl.-Ing. Stefan Schraml** will present the SPM. Stefan developed a Scanning Ion Conductance Microscope (SICM) in the course of his diploma thesis and Clemens is working on the photoreceptor of green algae for use in biocomputers.

14.12.2005: NO LECTURE

11.01.2006: NO LECTURE

First lecture 2006: January 18, 2006