AFM: Atomic Force Microscopy

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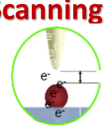
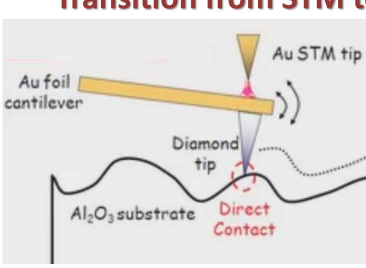
Scanning Probe Microscopy (SPM)



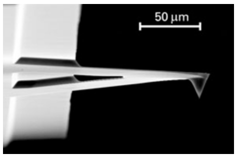
piezo-element (changes length at different voltages) converts the electrical energy input into mechanical energy

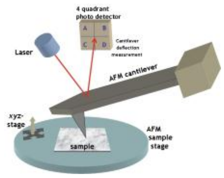
- **STM**: scanning tunneling microscope tunneling of electrons between probe and conducting surfaces (1981)
- **AFM**: atomic force microscope measuring the force of the probe on non-conducting surfaces (1986)

Transition from STM to AFM



AFM Cantilevers





Probes are typically made from Si_3N_4, or Si. Probes are coated with other materials for additional SPM applications .

- **Chemical force microscopy (CFM)**
- **Magnetic force microscopy (MFM).**

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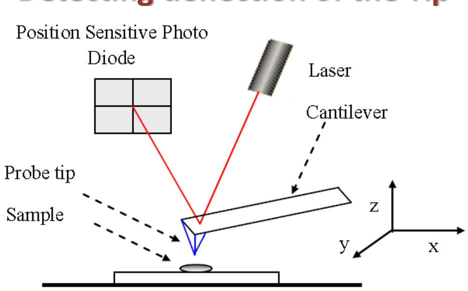
Agilent 5400 AFM System

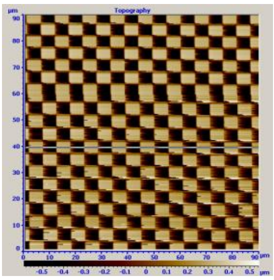
AFM Microscope and Vibration Isolation Chamber, Computer and Pico-View software

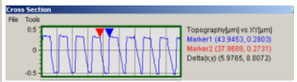
Detecting deflection of the Tip



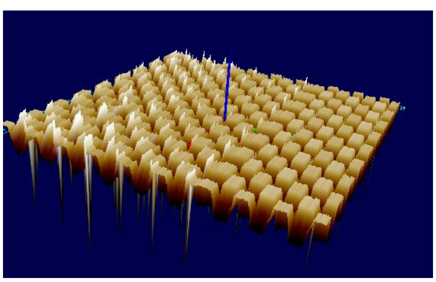
Marati et al. J Microscopy, 152 (1986)

Standard 5 µm Sample

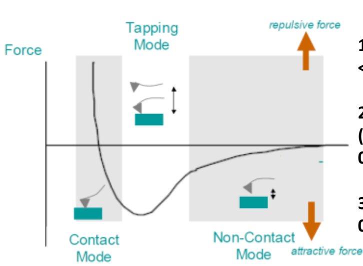




Standard 5 µm Sample
3-D Topography



Modes of Measurement



1) **Contact AFM**
< 0.5 nm separation

2) **Intermittent contact**
(tapping mode AFM)
0.5-2 nm separation

3) **Non-contact AFM**
0.1-10 nm separation

Contact Mode Imaging

Constant Height mode

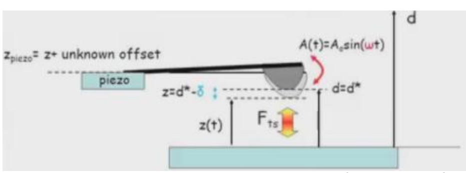
the tip is constantly adjusted to maintain a constant deflection.

Force-Curves Measurements

Force felt by the cantilever as the probe tip is brought close to - and even indented into - a sample surface and then pulled away can be used to determine chemical and mechanical properties such as adhesion, elasticity etc.

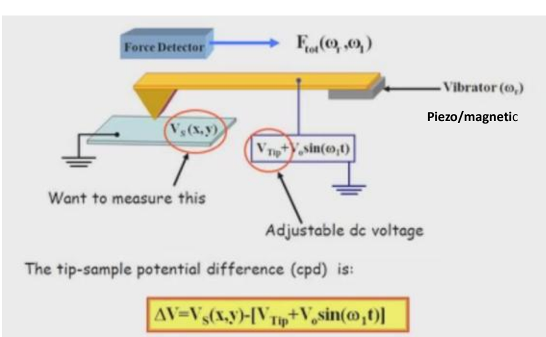
Dynamic Mode AFM

- Frequency Modulated FM-AFM (non-contact)



- Vibrations using a piezo element (AC mode)
- Vibrations using Magnetic (MAC mode)

Basic Concept

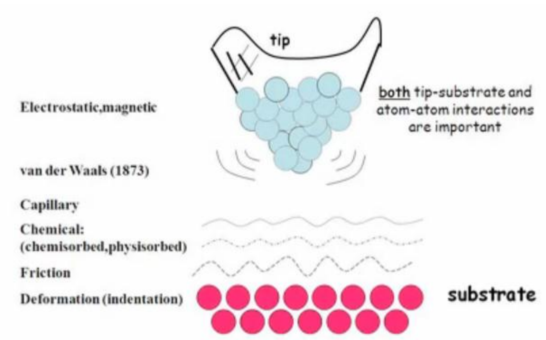


Acoustic Mode Imaging

AC Modes: vibrating the tip above the sample surface

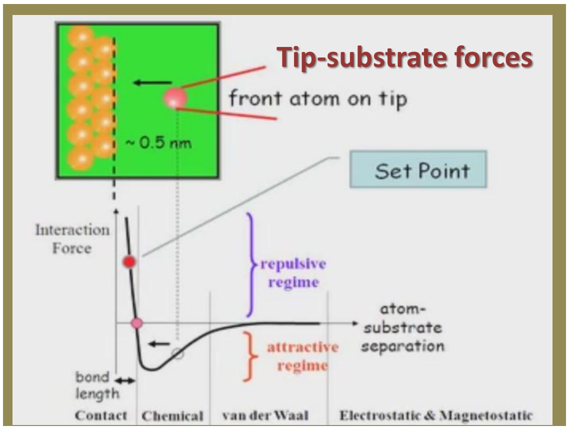
- **Acoustic AC (AAC) mode, using piezo- element to vibrate the tip**
- **AC (MAC) Mode AAC using a MAC magnetic controller to vibrate the tip**

Tip-substrate Interactions

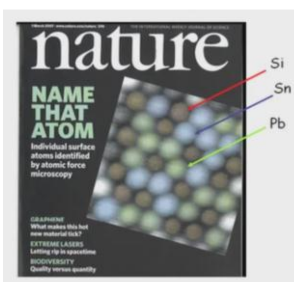


Atom/molecular/Electrostatic inter-ion Energies

1. Dispersion interactions (London)
2. Polarization forces (Keesom)
3. Dipole-induced dipole interactions (Debye)
4. Ion-ion interactions
5. Ion-dipole interactions
6. Dipole-dipole interactions
7. Angle-averaged dipole-dipole interactions



Atomic Scale Resolution



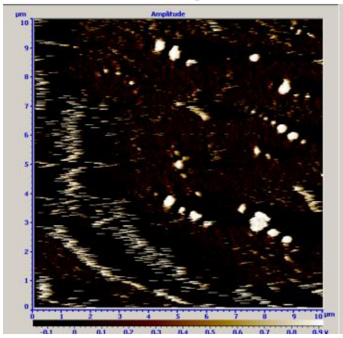
Nature 446, 64-67 (1 March 2007)

Historical Development

A selected Timeline for Scanning Probe Microscopy

- **1981** - Binnig and Rohrer invent the first scanning probe microscope - the Scanning Tunneling Microscope (STM)
- **1986 –** Binnig, Quate and Gerber invent the Atomic Force Microscope (AFM) - contact mode
- **1987** - non-contact scanning mode introduced
- **1988** - implementation of computer control
- **1989** - optical beam bounce method introduced
- **1991** – micro-fabricated tips
- **1993** - intermittent contact mode introduced

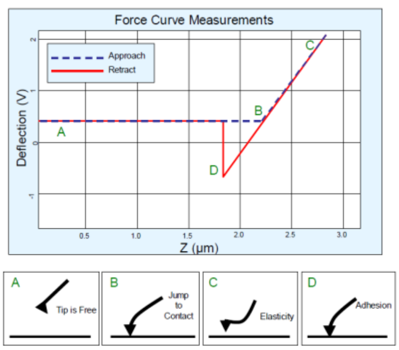
Asphalt Surfaces



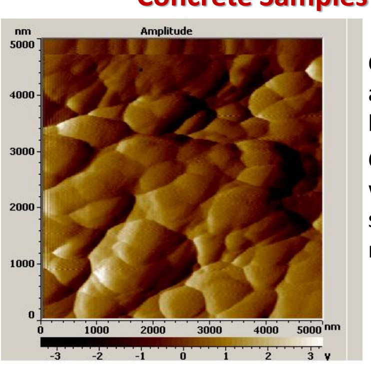
Asphalt samples are analyzed for elastic modulus:

Surface and mechanical properties

Elastic Modules Calculation: Contact Mode



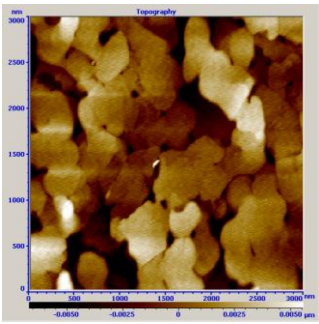
Concrete Samples



Calcium aluminate hydrate:

Concrete treated with alumina ns silica nanoparticles

Gold Surface

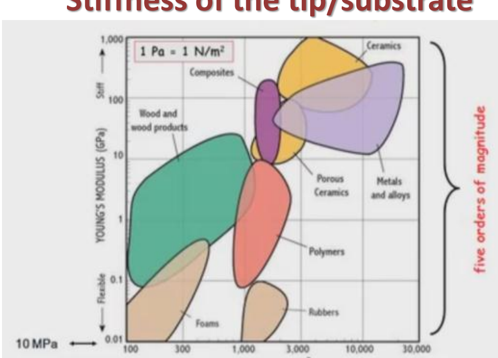


Microstructure of metals and alloys is related to mechanical strength

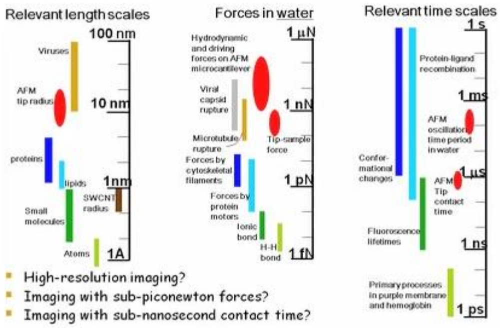
Biological samples

- Biological structures need to be in "native state" in liquids
- Problems with sample preparation: immobilizing on surface
- Attractive/repulsive forces complicated by solvent and other electrostatic forces
- Acoustic/tapping mode is the preferred on soft samples with little effects on the sample.
- Lower forces cuase less damage to soft samples such organelles and Protein-DNA complexes.

Stiffness of the tip/substrate



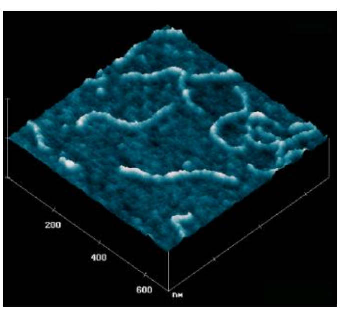
AFM Challenges for Biological samples



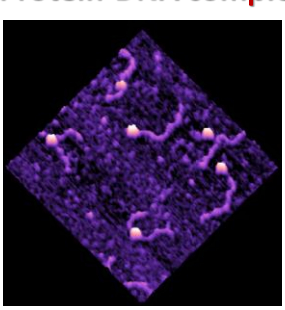
- High-resolution imaging?
- Imaging with sub-piconewton forces?
- Imaging with sub-nanosecond contact time?

* Sources: M. Daume, J Howard, Bray

DNA sample



Protein-DNA complexes



AFM of Mircotubules

Microtubules (P. J. de Pablo, Madrid)

AFM of ATP ase

ATPase molecular motors
J. Stahlberg et al (2001)

AFM vs. other Methods

a) **AFM vs. SEM** :AFM provides more topographic contrast and direct height measurements and conductive coating is not required as in SEM.

b) **AFM vs. TEM**: Three dimensional images can be obtained even without preparation of an expensive sample. More clear and resolute images can be obtained by AFM than a two dimensional view of cross sectioned TEM images.

c) **AFM vs. Optical Microscope**: AFM shows less unambiguous height measurements and in an optical microscope it depends on light reflectivity.

Bibliography

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