Atomic force microscopy and its applications

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Since its invention 20 years ago, Atomic Force Microscopy (AFM) has quickly grown into a widespread technique: from biology to surface sciences, through micro-electronics, polymers science or single molecule manipulations, the fields of application are as numerous as the operation modes of the apparatus. In this introductory course, we will study the principle of operation of this experimental technique from a physical point of view: to interpret images or force curves and get the most of the measurements, a good understanding of the underlying phenomena is undoubtedly useful. Beyond the physics of surfaces or objects studied, we will therefore tour many physical concepts, including optics, automatics, elasticity, non-linear physics, hydrodynamics, statistical physics, electrostatics, etc.

Below is a brief outline of the course, but we may explore different tracks depending on the audience affinities.

1 Introduction

A quick overview of what will be studied during this course...

1.1 Local probes to touch matter on a nano-metric scale

Tip: material, coatings, shapes, sizes.

1.2 Force sensor at atomic scales

Cantilevers, deflexion measurement.

1.3 Principle of operation

Piezo scanning, feedback loop mechanism.

1.4 Orders of magnitude

What AFMs can measure and what they can't : scan size, resolution, force sensitivity, environment, etc.

2 Cantilevers

2.1 Physical properties

Shapes and sizes, stiffness, coatings, tips.

2.2 Mechanical models

Euler-Bernoulli model, harmonic oscillator approximation.

2.3 Dissipation

Damping : Hydrodynamic load, Sader model, internal damping, etc.

2.4 Calibration of spring constant

Geometrical method, Fluctuation Dissipation Theorem and thermal noise calibration, Sader method.

3 Detection

3.1 Optical lever

Principle, computation of sensitivity, calibration

3.2 Interferometry

Setups, sensitivity

3.3 Non optical techniques

Historical method, piezo-resistive detection, tuning fork, etc.

3.4 Comparison of techniques

Pros and cons of detection strategies, force resolution.

4 Force spectroscopy

4.1 Relevant interactions

Van der Walls, electrostatic and capillary attractive forces, short range repulsive forces, functionalized tips and chemical bonds.

4.2 Force curve analysis

How to read a force curve and extract physical information.

4.3 Cantilever mechanical instability

Snap in and snap out of contact instability analysis.

5 Imaging: contact mode

5.1 Constant height scanning

Why this mode is seldom used.

5.2 Constant force scanning

Retroaction loop tuning, scan speed, topography images.

5.3 Resolution

Tip shape convolution, piezo corrections...

5.4 Lateral friction mode

Touching mechanical properties of surfaces.

6 Imaging: resonant mode

6.1 The cantilever at resonance

Driven harmonic oscillator, interaction with the surface.

6.2 Tapping mode

Retroaction loop tuning, topography and phases images.

6.3 Non-contact mode

An short introduction to Frequency-Modulation AFM (FM-AFM).

7 A few applications

7.1 Electrical modes

Lift mode, measuring dielectric properties, Kelvin probe force microscopy...

7.2 Material sciences

Some nice images or applications in a wide panorama : polymer sciences, crack propagation, atomic resolved surfaces, nano-fluidics, nano-lithography, semiconductors...

7.3 Life sciences

A neophyte random pick in an ocean of applications: single molecule force spectroscopy, complexed ADN imaging...

Usefull links

http://en.wikipedia.org/wiki/Atomic_force_microscope – A short introduction
http://www.padova.infm.it/torzo/Mironov_SPM.pdf – A full course
http://perso.ens-lyon.fr/ludovic.bellon/AFM/ – More links