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://www.padova.infm.it/torzo/Mironov_SPM.pdf – A full course
http://perso.ens-lyon.fr/ludovic.bellon/AFM/ – More links