Fundamentals of Atomic Force Microscopy
Part 2: Dynamic AFM Methods

Week 5, Lecture 6
Trends and Overview

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Cantilever dynamics in liquids

- Q factors reduce by 2 orders of magnitude compared to air, and resonance frequencies reduce by 3-5 times compared to air
- Strongly dependent on type of excitation used
- Acoustic mode excitation is problematic for quantitative force reconstruction however improvements are forthcoming
- Strong presence of higher harmonics distortions
Trends in dAFM techniques

- High-speed/video rate AFM
- Multi-frequency AFM
- Quantitative material property mapping
High speed

Enabling technologies

- High bandwidth Scanner, Z piezo,
- Fast phase detection
- Small cantilevers (< 20 microns)
- Excitation mechanisms (photothermal, high bandwidth magnetic)

M. J. Miles, Bristol, (APL, 86, 2005)
Infinitesima Inc.

www.asylumresearch.com

- M. Miles et al.
- T. Fukuma et al
- G. Schitter et al
- G. Fantner et al.
- H. Yamada et al
High speed - examples

- T. Ando, 7 frames per second
- Myosin V motor on actin

- G. Fantner, 20 lines per second
Higher harmonic imaging in liquids

Van Noort et al, 15, (Langmuir, 1999)
Preiner, Hinterdorfer et al, PRL, 99, 2007, also Ultramicroscopy, 2009
Bi-modal or dual AC AFM

- Bimodal or dual AC
  - Key insight is that the second mode $A_2, \phi_2$ varies in time
  - Thus $\phi_2$ not only measures dissipation but also conservative tip-sample interactions!
  - It becomes possible to see material contrast in the attractive regime!

Rodriguez and Garcia, APL, 84(3), 2004
Lozano and Garcia, PRL, 100(7), 2008
Lozano, Garcia, PRB, 79(1), 2009
R. Proksch, APL, 89(11), 2006
Bimodal or dual AC

FIG. 2. (Color online) HOPG graphite surface, 30 μm scan. The cantilever was driven at its fundamental (~69.5 kHz) and second eigenfrequency (~405 kHz). (a) shows the topography and (b) is the fundamental amplitude channel, used for the feedback error signal. The fundamental phase image (c) shows an average phase lag of ~34° indicating that the cantilever was in repulsive mode for the entire image. The second mode amplitude is shown in (d). The three dimensional rendered topography colored with the second mode amplitude is shown in (e). This method of display allows easy spatial correlation of the two channels.

Figure 7. (a) Bimodal AFM phase images (second mode) of IgM antibodies in water. The objects that show a pentagonal shape are marked by circles. The inset shows the frequency spectrum of a commercial cantilever in water. The dashed lines indicate the frequencies of the first and second flexural modes of the cantilever. They were determined by measuring the thermal noise spectrum. (b) Topography of an isolated antibody. (c) First mode phase image and (d) bimodal AFM phase image (second mode) of the same antibody.
Peak force tapping

- Fast F-Z curves (2-10kHz) with feedback on peak force
- Far below cantilever resonance so extraction of properties is easier
- Requires hydrodynamic drag correction
- Tip-sample snap in and pull out cannot be avoided

From Bruker Instruments Application Note 135
Peak force tapping - results

From Bruker Instruments
Application Note 135

Figure 4: Imaging of phytoplankton cell wall with a BioScope Catalyst AFM. Top left: electron microscopy image of a diatom of Dennis Kuniel, Astrogenics. Most of the PeakForce QNM channels provide a remarkable contrast and high-resolution imaging.

Figure 7: 75x75μm BioScope Catalyst and PeakForce QNM image of living HaCaT cells under oxidative stress. The cells react by rapidly synthesizing stress fibres to establish contacts with adjacent cells. Such dynamic processes can also be tracked by using this technique.
Conclusion

- Point mass model of dynamic AFM
- Analytical theory of dynamic AFM
- Simulating dynamic AFM using VEDA
- Reconstructing surface forces
- Dynamic AFM for electrostatics/magnetics/biology