ADHESION HYSTERESIS IN DYNAMIC ATOMIC FORCE MICROSCOPY

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The effects of adhesion hysteresis in the dynamic-dissipation curves measured in amplitude-modulation atomic force microscopy are discussed. Hysteresis in the interaction forces is shown to modify the dynamics of the cantilever leading to different power dissipation curves in the repulsive and attractive regimes. It is very common to find that dissipated power and dissipated energy are treated as equivalent terms in literature. Experimental results together with numerical simulations show that power dissipation, as measured in force microscopy, is not always proportional to the energy dissipated in the tip-sample interaction process [1].

Most real processes that occur when two materials are brought together involve energy dissipation or hysteretic phenomena. Understanding of the microscopic mechanisms of energy dissipation is then fundamentally relevant for a large variety of basic and applied problems (adhesion, contact formation, friction, wear …) and has motivated extensive theoretical and experimental efforts over a century [2]. The development of the atomic force microscope (AFM) opened a new way to study energy losses at nanometre scales. Phase shift variations, measured by recording the phase lag of the cantilever oscillation relative to the driving signal, are directly linked to energy dissipation processes [3-5]. At fixed feedback amplitude, phase contrast images are proportional to power dissipation maps which can potentially be translated into maps of substrate physicochemical properties [6].

Amplitude-modulation AFM (AM-AFM), often known as tapping mode AFM, has been shown to be a powerful tool for **qualitative** compositional/dissipation mapping. AM-AFM dissipation spectroscopy, based on the analysis of the dissipated power as a function of the cantilever oscillation amplitude, has been proposed as a way to identify specific energy-dissipation processes behind the compositional contrast [6]. However, despite of these important advances, the actual link between power dissipation and nanoscale surface properties is not well understood.

As a general approach, power dissipation in AM-AFM is naturally considered synonymous of energy dissipated per cycle. This energy can then be directly related to specific tip-surface interaction processes, number of chemical bonds, etc. In striking contrast with this apparently natural argument we show that **the dissipated power is not always proportional to the energy dissipated in the tip-sample interaction process**.

In this Letter we present AM-AFM dynamic-dissipation experiments performed on mica samples (at 0 % relative humidity) together with numerical calculations based on a point mass model. An excellent agreement between experiments and calculations is obtained assuming a simple mechanical hysteresis model where the energy dissipated in every contact process is a fixed quantity. Due to the bistable motion of the cantilever [7,8], the dissipated power strongly depends on the AFM operating regime [9]. While in the repulsive (high amplitude) regime power dissipation is constant (as expected from a fixed energy loss per cycle), in the attractive (low amplitude) regime both experimental and calculated power dissipation strongly depend on the cantilever oscillation amplitude.

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References:

[1] M. Köber, E. Sahagun, M. Fuss, F. Briones, M. Luna and J.J. Sáenz (to be published).
[2] Fundamentals of Friction: Macroscopic and Microscopic Processes, Edited by I.L. Singer and H.M. Pollock, NATO ASI Series E: Applied Sciences, Vol. 220 (Kluwer, Dordrecht, 1992).
[3] J.P. Cleveland, B. Anczykowski, A.E. Schmid, and V.B. Elings, Appl. Phys. Lett. 72, 2613 (1998).
[4] J. Tamayo and R. García, Appl. Phys. Lett. 73, 2926 (1998).
[5] P. D. Ashby and C. M. Lieber, J. Am. Chem. Soc. 127, 6814 (2005).
[6] R. Garcia, R. Magerle and R. Pérez, Nature Materials 6, 405 (2007).
[7] P. Gleyzes, P. K. Kuo, and A. C. Boccara, Appl. Phys. Lett. 58, 2989 (1991)
[8] B. Anczykowski, D. Krüger, and H. Fuchs, Phys. Rev. B 53, 15 485 (1996).
[9] E. Sahagún, P. García-Mochales, G.M. Sacha, and J.J. Sáenz, Phys. Rev. Lett. 98, 176106 (2007).

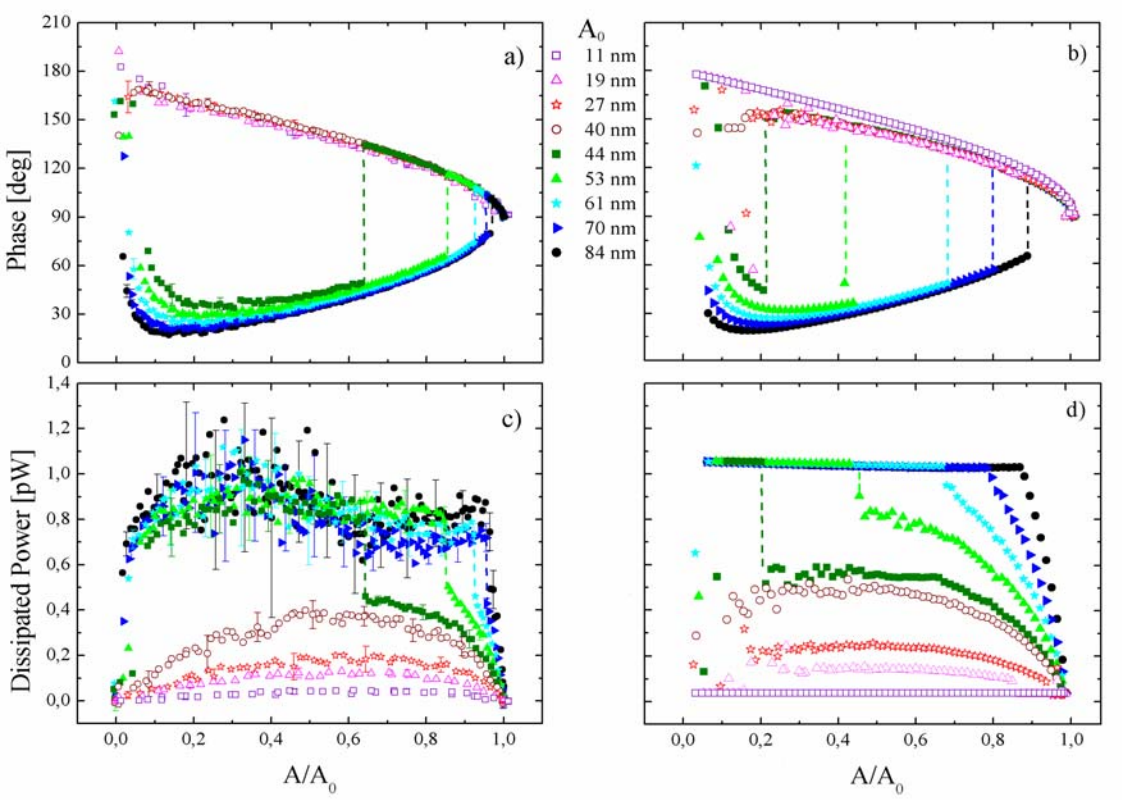

Figure 1a-d: Experimental (1a) and calculated (1b) phase shift and experimental (1c) and theoretical (1d) dissipated power versus the oscillation amplitude obtained as the tip-sample distance is reduced. Symbols correspond to different free oscillation amplitudes A_0. Experimental data were smoothed (average over 10 data points), the standard deviation is shown.