ENERGY DISSIPATION AT THE NANO-SCALE DUE TO CONTACT FORCES: A THEORETICAL AND EXPERIMENTAL STUDY BY MEANS OF DYNAMIC AFM

M. Koeber[1], E. Sahagún[2], M. Fuss[1], M. Luna[1], F. Briones[1], and J. J. Sáenz[2]

[1]*Instituto de Microelectrónica de Madrid (IMM-CSIC), C/ Isaac Newton 8, E-28760 Tres Cantos, Madrid, Spain*
[2]*Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*

Understanding energy dissipation processes at the nanoscale is a key issue in many applied and fundamental aspects of micro- and nano-technologies. In this field, the atomic force microscope (AFM) has emerged as the most versatile tool for studying energy losses at nanometer and even atomic [1] scales. The acquisition of energy dissipation images [2] in dynamic modes is interesting for several reasons. In first place, this energy can be potentially translated into substrate physical properties. The problem is that this translation is not yet fully understood. Several theoretical studies have tried to relate the energy loss with its physical source [3, 4]. In second place, energy loss images present higher contrast than other well known imaging methods (amplitude or phase imaging).

There exist several sources of cantilever energy dissipation: loss of kinetic energy due to taps with the surface, formation of stable bonds between tip and sample, movement of charges on tip or substrate, capillary process, etc. Recent theoretical work [3] suggested that the dynamics of dissipation in Amplitude Modulation AFM is the result of a nontrivial interplay between the energy dissipated in each tip-sample interaction process and the bistable motion of the cantilever. Bistability gives rise to two mechanical regimes: low amplitude (or attractive) regime and high amplitude (or repulsive) regime. The results indicate that while in the attractive regime dissipation is sensitive to elastic properties of the system (in particular to the free amplitude), in the repulsive regime it is independent of these and the energy dissipated per oscillation depends only on the energy that is lost in each contact oscillation.

The objective of this work is to experimentally evaluate the validity of this theoretical model where the only source of dissipation is through contact and it is the same for all the amplitudes. If no tap occurs, the system remains conservative. In the experiments zero relative humidity was chosen in order to avoid dissipation due to capillary condensation. The cantilever constant is 3 N/m, the resonance frequency 85.3 kHz. The substrate is recently cleaved mica. The results of experimental and theoretical dissipated power vs. normalized amplitude curves are depicted in figures 1 and 2. In both cases, dissipated power is obtained as the distance between the sample and the fixed end of the cantilever is reduced, for different free oscillation amplitudes. Assuming that the cantilever looses 56 eV per tap, there is a striking agreement between theory and experiments.

Although the low controlled humidity rules out capillary condensation of liquid necks, it is not possible to ensure that there is a single dissipation source. However, it is remarkable that a single simple dissipation source, the contact between tip and surface, is needed to simulate the whole experiment. Work is in progress to explain the noise at the maximum of the dissipated power.

References:

[1] Y. Sugimoto, P. Pou, M. Abe, P. Jelinek, R. Pérez, S. Morita, and O. Custance, Nature **446**, 64 (2007).
[2] J. P. Cleveland, B. Anczykowski, A. E. Schmid and V. B. Elings, Appl. Phys. Lett **72**, 2613 (1998).
[3] E. Sahagún, P. García-Mochales, G. M. Sacha, and J. J. Sáenz, Phys. Rev. Lett. **98**, 176106 (2007).
[4] R. Garcia, C.J. Gómez, N.F. Martinez, S.Patil, C. Dietz, and R. Magerle, Phys. Rev. Lett. **97**, 016103 (2006).

Figures:

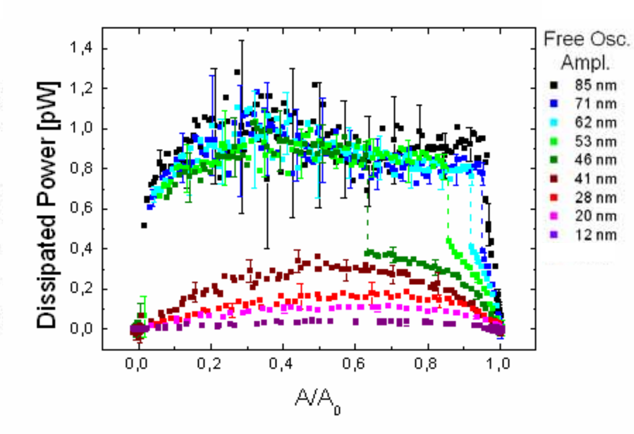

Figure 1: Experimental results of dissipated power vs. normalized amplitude for various free oscillation amplitudes.

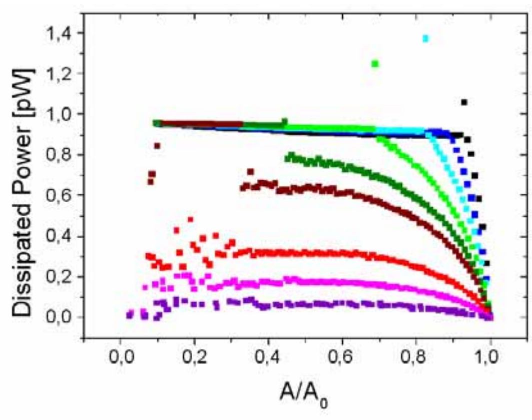

Figure 2: Theoretical simulation of dissipated power vs. normalized amplitude curves, for the same free oscillation amplitudes as in figure 1.