DISTANCE-VOLTAGE CURVES IN ATOMIC FORCE MICROSCOPY FOR ELECTROSTATIC NANOMANIPULATION EXPERIMENTS.

[1]J.Toset,[1]I. Casuso, [1]G. Gomila and [1]J. Samitier
[1]Departament d'Electrònica, Universitat de Barcelona and Laboratori de Nanobioenginyeria-CREBEC, Parc Científic de Barcelona, C/Josep Samitier 1-5, 08028, Barcelona, Spain
jtoset@pcb.ub.es

Electrostatic manipulation of conducting nanoparticles, e.g. gold nanoparticles, can be in principle performed with atomic force microscopy (AFM) by making use of electrostatic interaction forces, in a similar way as the experiments performed with other type of probes [1]. In these experiments a conducting AFM probe would be located at a given distance on top of the particle of interest and then a voltage bias would be applied beetween the tip and the nanoparticle. The electrostatic force acting between the nanoparticle and the tip causes the nanoparticle to desorb from the susbtrate and attach to the AFM tip. In order to perform these experiments a tight control of the distance betweem the tip apex and the nanoparticle as a function of the applied bias becomes necessary, in particular to prevent undesired collapse (snap-in) events. To assist in this control process, in the present communication we present a detailed modelling of the distance-voltage curves in Atomic Force Microscopy, including snap-in and snap-out events, together with its validation by experimental measurements.

The model considers the total energy of the system, which consists of the long range electrostatic energy between the probe and the susbrate, the short range Wan der Waals energy and the elastic energy of the cantilever bending. The long range electrostatic energy is modelled through the parallel of three capacitances corresponding respectively to the cantilever substrate capacitance, tip cone substrate capacitance and tip apex substrate capacitance [2]. This model generalizes simplified existing models [3], [4].

For a fixed distance above the surface (larger than some tens of nanometer) and small applied voltages (a few volts) the total energy of the system presents a single minimum, called electrostatic minimum, from which the actual tip apex-distance can be obtained (Figure 1a). At increasing applied bias, the cantilever bends even more and the tip appex starts feeling the short range Van der Waals interaction. Under this situation, a second minimum appears, but its value is still smaller than the previously existing minima, so the tip appex remains at the electrostatic minimum (Figure 1b). For a given applied volatge, the electrostatic minimum desappears and the tip advances quickly to the Wan der Vaals minimum, which is the single existing one under these conditions. This corresponds to the snap-in of the AFM tip onto the substrate (Figure 1c). The distance between the position of the electrostatic minimum before desappearing and the Van der Waals minimum after the collapse gives the snap-in distance. This value determines the minimum distance at which the tip appex can approach the surface before collapsing onto it. In order to decollapse the tip appex from the substrate, the applied bias has to be reduced untill the Van der Waals minimum desappears and the electrostatic minimu reapears (Figure 1d). This applied bias does not coincide in general with the applied bias before the snap-in event, due to the bistability of the system, what gives rise to a histeresis behaviour. The distance between the position of the Van der Waals minimum before desappearing and the electrostatic minimum after the decolapse gives the snap-out distance, that is, the distance between the tip appex and the substrate after the collapse, which is in general larger than the snap-in distance.

Distance-voltage curves performed with a platinum coated tip (Veeco Probes SCM-PIC k=0.2N/m) on a sputtered gold substrate confirm the predictions of the model (Figure 1e). We remark that the predictions of the model are quantitatively accurate for the approach curve, including the snap-in distance, while the decollapsing curve presents some small quantitative discrepancies, probably due to adhesion forces not included in the model.

References:

[1] K. Takahashi, H. Kajihara, M. Urago, and S. Saito. J. Appl. Phys. 90, 432 (2001)
[2] S. Hudlet, M. Saint Jean, C. Guthmann, and J. Berger Eur. Phys. J. B 2, 5-10 (1998)
[3] N. Tas, T. Sonnenberg, H. Jansen, R. Legtenberg, and M. Elwenspoek.
J. Micromech. Microeng. 6 385-397 (1996)
[4] Oscar H. Willemsen, Margot M. E. Snel, Laurens Kuipers, Carl G. Figdor, Jan Greve, and Bart G. De Grooth. Biophysical Journal 76, 716-724 (1999)

Figures:

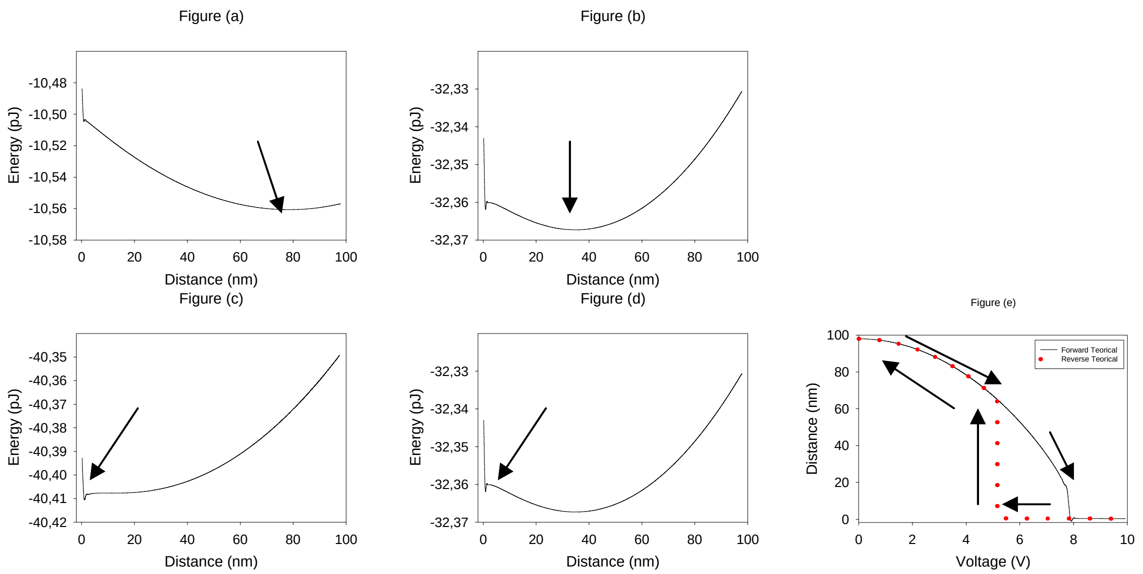

Figure 1: Energy profiles as a function of tip apex-distance (z) for a given tip apex-distance at zero applied bias (z_0=98 nm), and for various applied voltages between probe and substrate (a) 4V (b) 7V (c) 7.82V (d) 4V (e) Distance-voltage curve extracted from the model.

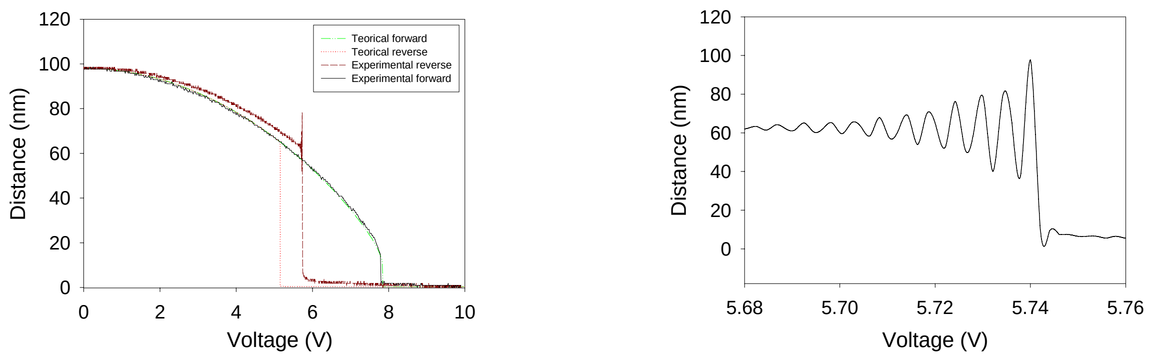

Figure 2: (a) Experimental voltage-distance curve performed with a platinum coated tip on a gold substrate. Note the good agreement between experimental results and theory. (b) Blow up of the damped oscillations following the snap-out event.