Electric-field assisted formation of nanometric liquid bridges in AFM

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One of the most recent developments in the AFM community is the ability to nanopattern a surface with any desired design. This is achieved by the oxidation of the surface on the nanometer scale by means of the application of a voltage pulse between an AFM tip and the sample. This technique is known as local oxidation nanolithography. There are basically two modes of operation in order to induce oxidation: contact and non-contact. In this work we devote our attention to the non-contact situation, where the oxidation is mediated by the formation of a nanometer scale liquid bridge between the AFM tip and the sample. The neck formation is induced by the electric field during the application of the voltage pulse. It is observed experimentally that, in order to form the bridge, and thus create the oxide motif, the voltage must exceed a certain threshold value.

In this work we analyze the formation of "electric-field-induced" liquid bridges from a simple theoretical model and compared with actual AFM experimental results. The formation process of the meniscus is as follows: the application of a voltage pulse deforms the initially flat thin-film of water creating a small bump (see Fig. 1(a)). The shape of the bump $\xi(\rho)$ will be that one that minimizes the total energy. The total energy (U_t) is the sum of four different contributions: (U_s) surface energy, (U_c) condensation energy, (U_{vdw}) van der Waals energy and (U_e) electrostatic energy.

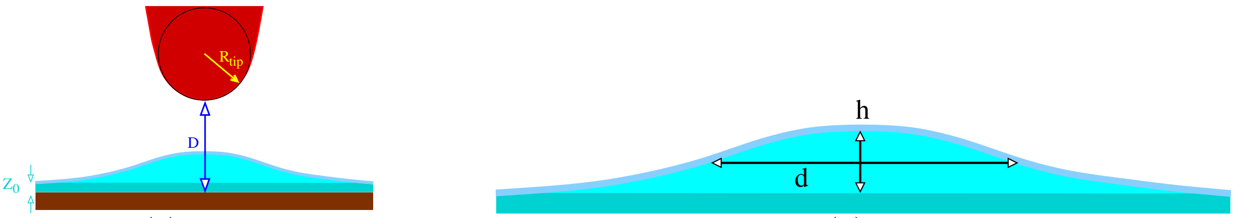

FIG. 1. (a) Schematic view of the tip-sample configuration. (b) Detail of the liquid bump, h and d are parameters used to describe ξ.

All contributions depend of the shape of the bump but U_c and U_{vdw} also depend on temperature and relative humidity and U_e is the only one that depends on the tip geometry and on the tip-sample distance.

In order to obtain the different contributions we parametrize the shape $\xi(\rho)$ as:

$$\xi(\rho : h, d) = \frac{h}{\cosh(\rho/d)} + z_0 \ , \qquad (1)$$

where h and d are depicted in Fig. 1(b).

The evaluation of the total energy reveals that beyond a critical value of the voltage V_c (V_c is the minimum voltage for which the bridge may exist) the most favorable situation is that tip and sample are connected by the bridge ($h = D - z0$). However, the energy presents a minimum for a given pair $\{h, d\}$, corresponding to the actual shape of the bump for that voltage (see Fig 2). The effect of increasing the bias voltage is to reduce the energy barrier. There is a voltage for which there is no minimum, i.e. there is no stable configuration for the bump and thus tip and sample are connected by the liquid meniscus. This is precisely the value of the threshold voltage V_{th}.

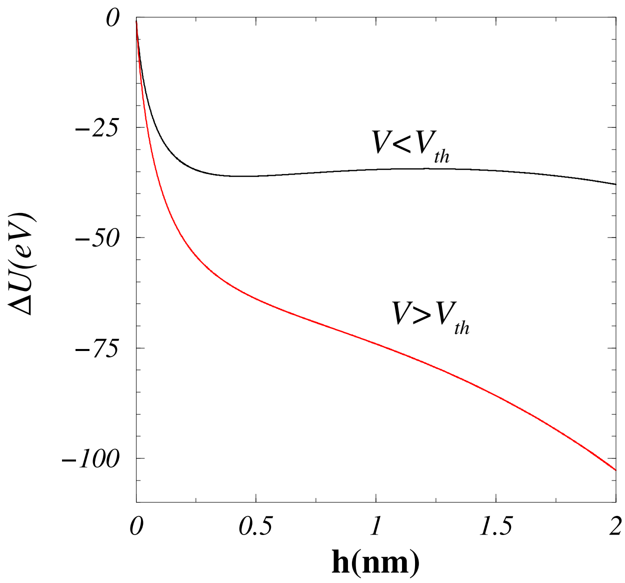

FIG. 2. $U_t(h)_{min}$ showing the stable minimum for $V < V_{th}$.