Formation Of Nanoscale Liquid Menisci In Electric Fields And Nanofabrication

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Local oxidation nanolithography is one of the most versatile AFM-based nanolithographies. Local oxidation by AFM is mediated by the formation of a nanometer scale water 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 V_{th}[1].

In this work we simulate the formation of "electric-field-induced" liquid bridges and compare with non-contact AFM experimental results for water and ethanol menisci. The formation process of the meniscus is as follows. The application of a voltage pulse deforms the thin-film of water adsorbed in the surface by creating a small protrusion. The shape of the protrusion □.□. 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 [2].

The tip-sample distance is modified due to the bending of the cantilever when the bias voltage is applied[3], playing a very important role in the total energy.
In order to obtain the different contributions we parametrize the shape □.□..as[3]:

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

where h is the height at the centre and d represents the width at half maximum. 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. However, the energy presents a minimum for a given pair $\{h, d\}$, corresponding to the actual shape of the bump for that voltage. 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 protrusion and thus tip and sample are connected by the liquid meniscus. This is precisely the value of the threshold voltage $V_{th.}$ The above behaviour has been observed with different liquids such as octane, octene, ethanol and propanol. We will also show that the chemical composition of the fabricated structures is liquid dependent which in turns allows the nanofabrication of different materials [4,5,6].

References

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