QUANTITATIVE NANOSCALE CAPACITANCE MICROSCOPY OF THIN DIELECTRIC FILMS AND BIOMEMBRANES

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Resumen

The measurement of capacitances at the nanoscale by means of scanning probe microscopies dates back to the seminal papers by Williams et al. [1], Matey and Blanc [2], by using an ultra high frequency capacitance meter, and by Martin et al. [3], by using a deflection-force meter. These techniques have evolved into the well known Scanning Capacitance Microscopy, used mainly for semiconductor dopant profiling, the Scanning Polarization Microscopy used to image very soft samples (specially very thin liquid layers) and various forms of electrostatic force microscopies. However, the main drawback of all these techniques has been their inability to provide quantitative values about the intrinsic dielectric properties of the samples under study (as for instance values of the dielectric constant measured at the nanoscale).

Recently, we have solved this difficulty for the case of thin dielectric films and biomembranes. On the one hand, we have implemented a capacitance meter on a commercial atomic force microscope able to provide direct quantitative values of the probe-sample capacitance [4]. On the other hand we have developed a detailed calibration procedure in which stray capacitance contributions are accounted for and the electric tip radius can be precisely determined (Fig. 2) [5,6]. Finally, we have developed a simple analytical formula to interpret the capacitance measurements performed on thin dielectric films (Fig. 1) [7], thus enabling us to extract in a quantitative way the dielectric constant of the samples being measured at the nanoscale. The technique has been succesfully applied to thin silicon dioxide films [6] and to purple membrane monolayers [8].

Finally, we have verified that similar results can be obtained by means of electrostatic force measurements, although careful, and sometimes subtle calibration procedures have to be followed, thus opening the possibility to measure the dielectric constant at the nanoscale by means of almost any commercially available atomic force microscope [9].

Referencias:

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Figuras:

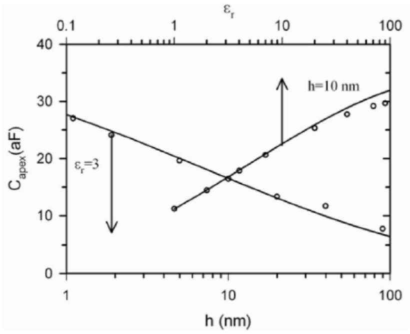

Figure: 1. Apex capacitance calculated for the probe in close contact with a dielectric film as a function of the relative dielectric constant Cr for a fixed dielectric thickness of h=10nm (upper horizontal axis) and as a function of dielectric thickness for a fixed relative dielectric constant of Cr = 3 (bottom horizontal axis) (tip radius R = 100 nm and cone angle 30º). Symbols: numerical simulations. Solid lines: theoretical curves given by the analytical formula.

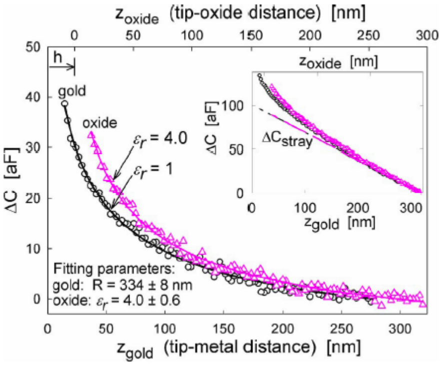

Figure: 2. Measured apex capacitance variation vs tip-sample distance taken on a 23-nm-thick and 1 x 1 µm2 area SiO2 layer (triangles) and on a gold surface (circles) close to the oxide. The lines are the theoretical fitting to the analytical formulae for a metallic and dielectric sample, respectively. The curve on the metallic sample provides the value on the tip radius. Inset: corresponding curves of the measured capacitance before subtraction of the stray contribution showing a stray slope of kstray=0.318 aF/nm in both curves (dash line). (spring constant of 40N/m, applied ac voltage of 1 V amplitude and 110 kHz frequency).