Three-Dimensional Modeling of Electrical Scanning Probe Microscopy Problems

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Abstract

Electrical scanning probe microscopy (SPM) techniques, such as electrostatic force microscopy, nanoscale impedance microscopy or scanning near field microwave microscopy, are a relatively new branch of microscopy techniques that can generate images of the nanoscale electrical properties of samples (conductivity, permittivity, charge, etc.). These techniques scan the surface of a sample (bacteria, cells, polymer nanocomposites, nanomaterials, etc.) with an electric potential applied between tip and sample and provide electrical images with nanoscale spatial resolution [1-3]. The established types of scanning probe microscopy have been proposed as a novel family of non-invasive techniques for medical diagnosis, as well as, non-destructive methods of quality controls for the MEMS and nanotechnology industries.

The techniques of exploration performed by the electrical SPMs are constantly updated in order to improve the resolution of the electric images. We draw particular attention in this presentation to three different imaging modes implemented with these microscopes. First, the single point approach curve method (ACM) (see Figure 1), when the tip is approached vertically to the sample. Second, the constant height method (CHM) (see Figure 1), when the tip movement is performed at a constant distance from the substrate. And third, the lift imaging method (LM) (see Figure 1), when the tip scans the sample surface following the shape of the sample at a constant tip-sample distance.

Here, we present a general framework of the three-dimensional modeling of these electrical SPM modes using COMSOL Multiphysics® software. The AC/DC Module of COMSOL Multiphysics was used to solve the static electric field between tip and sample according to the scan technique considered. A cylindrical domain with an infinite elements layer on the boundary is defined. From the integration of the charge density on the probe surface capacitance images can be derived (see Figure 2, top raw), while integration of the Maxwell stress tensor can provide images of the capacitance gradient (see Figure 2, bottom raw).

The results presented here shown that the experimental measurements can be interpreting with the theoretical calculations performed in COMSOL. In addition, the simulations allow the pre/post-

processing of the experimental data.

Reference

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2. L. Fumagalli et al. Label-free identification of single dielectric nanoparticles and viruses with ultraweak polarization forces, Nature Materials 119, 743-826, (2012).

3. D. Esteban-ferrer et al. Electric Polarization Properties of Single Bacteria Measured with Electrostatic Force Microscopy, ACS Nano 8, 9843–9849 (2014).

Figures used in the abstract

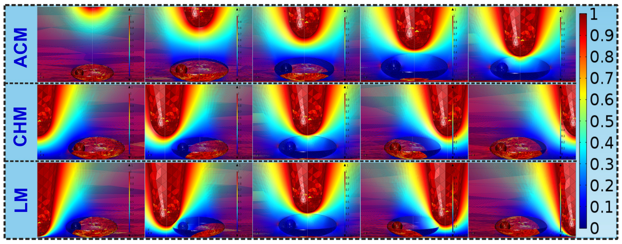

Figure 1: Electric potential distribution obtained from the COMSOL simulations for 1V applied for the case of tip-bacterium model. Three different methods of exploration performed by the electrically biased SPM probe: approach curve method (ACM), constant height method (CHM) and lift-mode (LM).

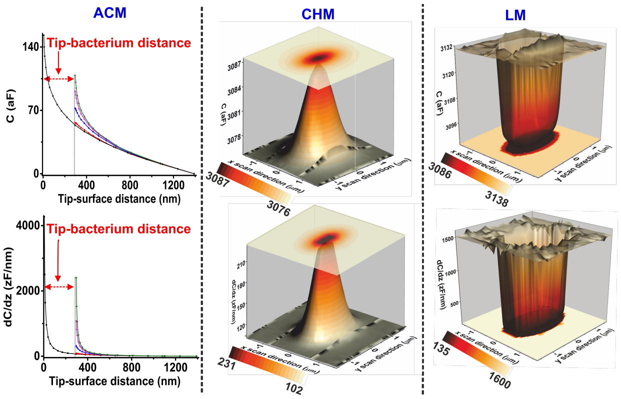

Figure 2: Capacitance (upper raw) and capacitance gradient (bottom raw) data generated by the different methods of exploration (from left to right): approach curve method (ACM), constant height method (CHM) and lift-mode (LM)) performed by COMSOL, for the case of a bacteria-tip model.

Figure 3

Figure 4