Abstract

TITLE: Method for Determining the Electrical Shape of a Scanning Probe Microscope Tip

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ABSTRACT BODY:
Abstract Body: Electrical scanning probe microscopes (eSPMs), such as the scanning capacitance microscope (SCM) and the scanning Kelvin force microscope (SKFM), measure the electrical properties of a virtual device formed between the tip and the sample. Like all electrical measurements, the measured electrical parameters depend on the electrode shapes (the tip and the electrically active part of the sample), and the fundamental electrical properties (dielectric constant, conductivity, etc.) of all the material between the electrodes. In general, the details of the tip electrical shape are not known, and the electrical shape can differ substantially from the physical shape, especially for co-axially shielded probe tips.

The eSPM tip shape effects the measured contact potential difference (CPD) profile of measurements of electrical field gradients with SKFM. A different response is measured depending on the angle that the tip crosses the boundary in potential. We have determined a method of extracting the electrical tip shape from measurements on well-known structures which produce a calculatable electric field gradient. The method was derived using two-dimensional COMSOL simulations of CPD profiles across abrupt boundaries in potential. An estimate of the tip width at the cantilever is obtained from the inflection points of the simulated response. Knowing the tip length, the cantilever tilt angle, and the determined tip width, a "blind" reconstruction of the details of the tip shape can then be obtained from the $\Delta\varphi/\Delta x$ using an analytical expression. The quality of the reconstruction is best near the tip apex. The estimate of the tip shape can be improved by inserting the initial determined tip shape into COMSOL and recalculating the CPD profile. An adjusted tip shape can then be derived using the difference between the initial CPD profile and the recalculated profile.

For real three-dimensional tips, two types of test structures were prepared. The first structure consists of alternating Au and Pt regions with abrupt boundaries formed on an extremely flat mica surface. The second structure consists of pairs of independent microfabricated electrodes separated by a small distance and beneath a thin cover layer of dielectric. A 2D cross-section of the 3D tip at the angle of scan across the test structure can be obtained using the above method. By rotating the sample and scan angle, multiple cross-sections across the tip can be obtained and a three-dimensional tip reconstructed.

Knowledge of the actual electrical tip shape can be used to better understand electric field gradients measured with eSPMs and to determine the suitability of various types of conducting SPM tips for electrical measurements. For co-axially shielded tips, the above technique is the only way to get an estimate of the electrical tip shape. Electrical tip shape may also prove useful in inverse modeling to improve the accuracy and spatial resolution of images of electrical properties with eSPMs.