Piezoresponse Force Microscopy: Fields below the Surface

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In recent years, Piezoresponse Force Microscopy (PFM) has become the primary tool for the characterization of ferroelectric materials at nanoscale dimensions. Application of dc bias to the tip allows control of the local polarization state, providing the capability for local spectroscopic measurements and polarization patterning. Quantitative interpretation of PFM hysteresis loops and polarization switching data requires knowledge of the tip-induced electric field and stress distributions inside the ferroelectric material that can then be used to estimate the electrostatic and mechanical contribution to the domain energy. Here, we report the first analytical solution composed of elementary functions of the coupled electromechanical problem for piezoelectric indentation by a realistic SPM probe. These solutions are used to derive the electric field and strain distribution inside the ferroelectric material, providing a complete continuum mechanical description of the PFM imaging mechanism. Field distributions provide a rigorous basis for the quantitative analysis of PFM spectroscopy and switching data. It is shown that the dielectric gap formation at the tip-surface junction due to surface contamination significantly affects the PFM imaging mechanism. Preliminary results of PFM imaging under controlled atmosphere conditions are discussed. In the second part, the frequency-dependent electrical (stray capacitance) and mechanical (buckling) non-local contributions of a typical cantilever to the PFM signal are analyzed and the guidelines for the optimal choice of the PFM probe are delineated.