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Quantitative Electromechanical and Elastic Measurements by SPM

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In the last decade, a number of nanoindentation and Scanning Probe Microscopy (SPM) based techniques for local characterization of elastic and electromechanical properties on the nanoscale have been suggested. The image formation mechanism in these techniques, including Piezoresponse Force Microscopy (PFM), Atomic Force Acoustic Microscopy (AFAM) and Ultrasonic Force Microscopy (UFM), as well as in nanoindentation, is ultimately based on the bias-dependent contact mechanics of the tip-surface junction. We demonstrate local electromechanical and elastic imaging and spectroscopy for a broad range of materials systems from ferroelectric to biological systems. To quantify these data, the nanoelectromechanics of the tip-surface junction, including the structure of coupled electroelastic fields and stiffness relations, is analyzed for flat, spherical, and conical indenter geometries. Exact solutions in elementary functions for electroelastic fields inside the material are obtained using the recently established correspondence principle between the elastic and the piezoelectric problems. The stiffness relations fully describe the indentation process and relate indentation depth, force and bias to the relevant material properties, and indenter parameters. This extends the results of Hertzian mechanics to piezoelectric materials. The structure of the electroelastic field yields a quantitative measure of the signal generation volume in electromechanical SPMs and also provides a quantitative basis for the analysis of tip-induced polarization switching and local hysteresis loop measurements. An approach for combined imaging of elastic and electromechanical properties of materials is presented. It is shown that for a transversally isotropic material this provides the most comprehensive materials properties achievable. It is also shown that that the indenter shape, generally unknown in SPM experiments, can be reliably calibrated, thus providing a pathway for quantitative electromechanical and elastic studies of piezo- and ferroelectrics at the nanoscale.

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