Piezoresponse Force Microscopy:
Quantitative Analysis of Nanoscale Ferroelectric Hysteresis Loops

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In the last several years, Piezoresponse Force Microscopy has established itself as one of the primary techniques for the nanoscale characterization of ferroelectric materials. The applications of PFM include vertical and lateral polarization imaging, tip-induced polarization switching, nanodomain patterning and nanoscale hysteresis loop measurements. While the shape of the macroscopic hysteresis loops is determined by the time-dependent nucleation of multiple domains at the defect sites in the weak uniofrom field as described by Kolmogorov-Avrami and Ishibashi theories, the mechanism for hysteresis loop formation in PFM is fundamentally different. Here we analyze the mechanism for hysteresis loop formation in the PFM. It is shown that the high concentration of electric field below the tip results in the domain nucleation irrespectively of the presence of defects sites. The hysteresis loop shape is determined by the formation of the transient domain below the tip, the size of which increases with the tip bias. This allows quantitative description of the hysteresis loop shape. This analysis is applied to investigation of the local switching properties in $SrBi_2Ta_2O_9$ (SBT) thin films. Variations in PFM contrast of individual grains due to their random crystallographic orientation are consistent with the grain switching behavior examined via vertical and lateral hysteresis loops. Dependence of the hysteresis loop parameters on the grain crystallographic orientation is analyzed. It has been found that grain deviation from the ideal (010) orientation when the polar axis is normal to the film plane results in the decrease of the PFM signal and increase of the coercive voltage in agreement with theoretical predictions.

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