"Strange Ferroelectrics": Why so Many Materials Appear to Show Piezo/ferroelectric Behaviors During Nanoscale Measurements

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The last 20 years has seen an explosion in research into nanoscale ferroelectrics (typically, thin-films but also nanoparticles and other nanostructures), driven by both increased technological applications (e.g., the development of FeRAM), as well as fundamental physics questions related to size effects, mesoscale disorder, domain wall motion, etc. This growth was facilitated by the development of synthesis techniques, including pulsed laser deposition and molecular beam epitaxy, allowing unit-cell level precision in growth and producing films of compounds that are difficult to synthesize in bulk. In parallel, the introduction and expansion of piezoresponse force microscopy allowed imaging domains and domain walls in nanoscale ferroelectrics, and the introduction of a multitude of PFM-based spectroscopies saw substantial insights gained over the past decade into the behavior of ferroelectric materials at sub 100-nm length scales.[1]

With this broad adoption of PFM however came an increasing number of reports of piezo- and ferroelectric behaviors on systems that are not expected to be ferroelectric (i.e., do not show such behavior in bulk), or where size-effects are predicted to suppress ferroelectricity. These ferroelectric-like behaviors include full hysteretic switching in piezoresponse (generally with unsaturated hysteresis loops), a continuum of polarization states, pressure-induced switching, and generation of long-lived states that do not relax via domain wall motion.

In this talk I will outline some of the common features of such 'strange ferroelectrics'[2], and outline the various signal contrast mechanisms in electromechanical detection via atomic force microscopy (AFM). We proceed to show how even non-ferroelectric materials can display signatures of this behavior in PFM-based studies, and then outline some strategies as to how these can be separated from piezo/ferroelectric phenomena, focusing on a recently developed contact Kelvin Probe Force Microscopy (cKPFM) technique.

We provide a broad overview of concerns related with interpretation of data acquired during PFM on nanoscale ferroelectrics, and show recently obtained data from combined AFM and time-of-flight secondary ion mass spectrometry suggesting chemical changes during scanning. We then provide a survey of the possible mechanisms at play, and discuss strategies to measure and quantify both the electrostatics and piezoelectric responses on the road towards full quantification of piezoelectric coefficients in PFM, and finally towards answering the question "but is it really ferroelectric?"

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References

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