

Investigation of Ferroelectricity using Advanced Microscopy

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Backgrounds:

Ferroelectric materials, characterized by their ability to exhibit spontaneous electric polarization switchable under applied electric fields, manifest intricate interactions among electrical, thermal, and mechanical properties. These materials, pivotal in various applications such as spintronics, computing, communications, memories, actuators, motors, and sensors, undergo changes in behavior and properties in response to factors like temperature, electric field, pressure, and strain. To explore ferroelectricity, some basic techniques, such as single-crystal X-ray diffraction, second harmonic generation measurement and dielectric measurement, were used to investigate the crystal structure, symmetry and dielectric anomaly. However, it is difficult to accurately determine whether the crystal structure is centrosymmetric or non-centrosymmetric down to nanoscale level by virtue of these basic measurement. This has hindered the progress of investigating the ferroelectricity related properties in the past.

Methods:

Advanced microscopies including Piezoresponse Force Microscopy (PFM) and Scanning Transmission Electron Microscopy (STEM), have been regarded as powerful approaches for evaluating the physical properties of materials down to nano, or even atomic scale. PFM has already been an essential method to investigate materials with piezoelectric properties. Especially, PFM shows its superiority in the studies of local non-destructive visualization of ferroelectric domain structures. In addition, Scanning Transmission Electron Microscopy (STEM), a fundamental tool in nanoscience, facilitates the acquisition of atomic-scale images and spectra. These images and spectra provide information on the structural and chemical properties of the studied nanostructures. As a result, STEM aids in a comprehensive understanding of the physical properties of functional materials at the atomic level. Consequently, combining advanced microscopies such as PFM and STEM has been shown as a powerful approach for evaluating the ferroelectric properties down to nanoscale even atomic level.

Results:

This study delves into a comprehensive examination of several ferroelectrics including organic-inorganic hybrid perovskites and traditional inorganic ferroelectrics utilizing advanced microscopies including PFM and STEM. These approaches enable a profound understanding of the intricate relationship between domain structure, electric polarization, lattice structure, and electronic states, thereby offering control over the nuanced mechanisms of ferroelectrics. Leveraging advanced microscopy including PFM and high-resolution STEM, we precisely investigated ferroelectric domain structures, the atomic and electronic structures of ferroelectric materials, shedding light on the impacts of domain properties, atomic displacements, and electronic configurations on ferroelectrics.

Conclusion:

The findings of this research hold significant implications for deepening the understanding on the ferroelectric properties, including changes in the ferroelectric domain structure and atomic level displacements, potentially paving the way for the creation of more efficient and reliable memory storage, sensors, and energy converters. We anticipate that our research will establish a robust foundation for the examination of ferroelectricity and other complex functional materials down to atomic level.

Keywords:

Ferroelectrics, thin Films, Advanced Microscopy