PRACTICAL WORKS - Course: Surface analysis, part I - scanning probe microscopy
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Within the module "Scanning probe microscopy" two TPs are proposed.
Each TP represents a project with a duration of 5 weeks for a group of 3 persons.

TP 1. Surface structure, ferroelastic and ferroelectric domains in PZT epitaxial layers

Objectives : Analysis of the impact of the local pressure on the surface structure and domain patterns in lead zirconate titanate films. The study is done by AFM (topography, piezo-force microscopy, conductive AFM). The measurements include control/change of domain pattern using local pressure or electric field applied through the probe, mapping conduction and local electromechanical response, probing surface charge via KPFM.

Acquired skills and studied techniques:
-Basic AFM operation, mounting and alignment of probes, configuring measurements
- AFM contact mode /non-contact mode – specific approaches for quick time-efficient scans and enhanced resolution imaging
- electro-mechanical coupling: PFM measurements, nanoscopic mapping for ferroelectric and ferroelestic domains, analysis of polarization patterns and switching dynamics, PFM mapping, PFM spectroscopy and coercive field mapping,
-conductive AFM
-KPFM

Support information: relevant papers and application notes will be distributed to the group members, an example of the approach and analysis of results is presented in the references below.

Lead zirconate titanate (PZT) is one of the most studied multiferroic material used for a broad range of applications including piezoelectric actuators, scanners, non-volatile memories, ultrasonic diagnostics etc. Ferroelectric materials tend to form polarization domains in order to minimize their electrostatic or mechanical energy. The resulting domain pattern may vary depending on different factors and the knowledge of the domain structure is important for many applications. Here we study both ferroelectric and so-called ferroelastic (driven by strain) domains formed in thin epitaxial PZT films and investigate the interplay between the domain structure and transport properties. Recently some unexpected properties of the polarization domains, such as metallic conductivity in the domain walls have been discovered. Further exploration of this phenomenon is currently under way, and some samples fabricated for this project will be tested in the framework of the present TP.

Refences:

Risch, F.; Tikhonov, Y.; Lukyanchuk, I.; Ionescu, A. M.; Stolichnov, I. Giant Switchable Non Thermally-Activated Conduction in 180° Domain Walls in Tetragonal Pb(Zr,Ti)O3. *Nature Communications* **2022**, *13* (1), 7239.

Stolichnov, I.; Feigl, L.; McGilly, L. J.; Sluka, T.; Wei, X.-K.; Colla, E.; Crassous, A.; Shapovalov, K.; Yudin, P.; Tagantsev, A. K.; Setter, N. Bent Ferroelectric Domain Walls as Reconfigurable Metallic-like Channels. ***Nano Letters*** **2015**, *15* (12), 8049.

TP 2
Multiferroic Bismuth ferrite ($BiFeO_3$) - BFO – polarization memory effects and conductive domain walls

Objectives : Analysis of polarization reversal, domain patterns, memory effects and conduction in rhombohedtral BFO.

Acquired skills and studied techniques:
-Basic AFM operation, mounting and alignment of probes, configuring measurements
- AFM contact mode /non-contact mode
- electro-mechanical coupling: PFM measurements, nanoscopic mapping of polar domains, analysis of polarization patterns vs. microstructure, PFM mapping, nanolithography for ferroelectric domain patterning, local probing of polarization switching, multimode PFM + cAFM mapping

Supporting information: PhD Thesis . Monika_ Iwanowska_TH5654.pdf; relevant papers

Bismuth ferrite (BFO) is an archetypical multiferroic material, which is also a kind of lead-free ferroelectric material that displays many excellent properties, including a large residual ferroelectric polarization. Moreover, the narrow band gap of BFO results in relatively high leakage currents, which enable a cross-talk between the ferroelectric and transport properties.

In this TP we learn how to use multi-mode AFM in order to explore the interplay between the polarization and transport properties. The work involves the study of microstructure and roughness (AFM topography mapping in contact and tapping modes), mapping polarization domain structure (PFM), and switching-spectroscopy PFM. Conduction mapping performed concurrently with PFM enables an insight into the transport enhanced by domain walls of different types. Based on the collected data, the group members prepare a report with analysis of microstructure, electromechanical response, switching properties and domain-wall conduction.

References

1. J. Seidel et al. Domain wall functionality in BiFeO3, Phase transitions, 86,1, 53-66 (2013).
2. Monika Iwanovska, PhD thesis, EPFL, TH5654