Piezo-Response Force Measurements on Ferroic Oxide Films

The renaissance of multiferroics in which at least two ferroic or antiferroic orders coexist, is motivated by fundamental aspects as well as by their possible applications in the field of spintronics. Magnetoelectric coupling allows for instance the reversal of the ferroelectric polarization by a magnetic field or the control of the magnetic order by an electric field. Most of the ferromagnetic-ferroelectric compounds exhibit both orders at low temperature.

Piezo-response Force Microscopy (PFM) is a variant of contact mode AFM. While the tip is in contact to the sample, AC voltages are applied to the conducting AFM tip, which result in height changes at the frequency of the excitation thanks to the inverse piezoelectric effect. The sample surface vibration is detected by de-modulating the recorded tip height. The vibration amplitude is related to the vertical projection of the ferroelectric polarization, the vibration phase lag is 0° or 180°, depending on whether the polarization is pointing up or down. The PFM mode gives an image of the ferroelectric structure at nanoscale.

In the measurements presented here, K. Bouzehouane and S. Fusil from the CNRS Unité mixte de Physique CNRS/Thales show PFM data taken on a layered heterostructure (150 nm $BiFeO_3$-Mn on top of 35 nm of $SrRuO_3$ on a $SrTiO_3$ (001) substrate) recorded at 82 K with a standard attoAFM I. The multiferroic material $BiFeO_3$ (also BFO) is both magnetic and strongly ferroelectric even at room temperature. It is therefore an ideal candidate for PFM measurements.

While the topography scan of the sample shows a fairly flat sample (see Fig. 1), the simultaneous PFM signals show clearly ferroelectric domains. The external part of these images corresponds to the pristine state and the center part to written square shaped domains (see Fig. 2). A 1 x 1 µm² and a second, 45° rotated square were written with an applied DC tip voltage of ±15 V. The recorded phase shows the different orientations of the domains with approximately 180° phase difference, as expected in parasitic free acquisition conditions. In the right image, one can see that the PFM amplitude goes to zero at the intersection of these structures, as expected for vibration nodes between two antiparallel domains corresponding to domain walls.
Figure 3 is a typical piezo-response hysteretic cycle acquired with an AC+DC bias applied to the tip and giving the coercive switching biases at 82 K. Note that the piezo-response of BFO is a few tens of picometers, attesting for the low noise sample environment.

Images and data courtesy of K. Bouzehouane and S. Fusil, Unité Mixte de Physique CNRS/Thales, Paris, France.

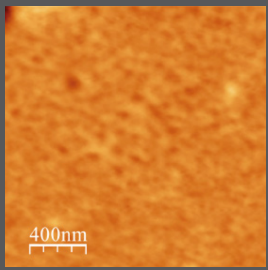


Fig. 1: Topography image of the sample surface. The height contrast (black to white) is 15 nm.

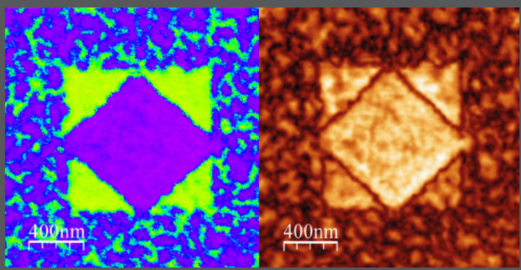
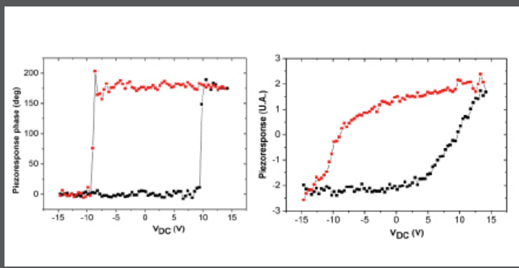


Fig. 2: Piezo-response phase (left, 0-180° contrast) and amplitude (right, a.u.) map of the sample at 82 K. Two squares have been written, a 1 x 1 µm² and a smaller, rotated one with ±15 V tip voltage. Note that the amplitude goes to zero in the domain walls. The outside area shows natural domains.



Piezo-response hysteretic cycles of the sample at 82 K: phase (left) and amplitude behavior (right graph).

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