NANOSCALE PROPERTIES OF RELAXOR CERAMICS VIA SCANNING PROBE MICROSCOPY

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Relaxor ferroelectrics (with smeared phase transitions) are highly inhomogeneous systems [1]. These materials are characterized by anomalies of the susceptibilities over an extremely wide range of temperatures. The unique properties of relaxor ferroelectrics offer strong possibilities for their practical application [2]. Effects of La impurities on the microstructural and property changes have recently been reported for $Pb_{1-3x/2}La_x(Zr_{1-y}Ti_y)O_3$ with Zr/Ti ratios of 65/35. Increasing La impurity content was found to induce a common sequence of domain like states in the rhombohedral ferroelectric $x/65/35$ compositional sequence including: normal nm-sized domains, tweed like precursors, and polar nanodomains (or clusters).

In this work we present the experimental SPM study of the geometry of the nanoscale domain structure in classical lead zirconate-titinate relaxor ceramics (PLZT $x/65/35$) with La concentration 8 and 9.5%. Domain images were obtained by the SPM method using a commercial atomic force microscope (Multimode, Nanoscope IIIA, Digital Instruments). The SPM method is based on the detection of thickness oscillations of ferroelectric materials under an ac voltage applied between the SPM tip and the bottom electrode in a conventional contact mode [3]. The amplitude of the measured vibration is proportional to the effective longitudinal piezoelectric coefficient, while its phase depends on the orientation of the out-of-plane component of the polarization vector.

Figure 1 show topography and piezoresponse images of PLZT ceramics at room temperature. Figures 1 (b,d) is domain structures of the PLZT ceramics using the SPM in piezoresponse mode, which clearly reveals fingerprint patterns related to domains with antiparallel polarization [4]. These stripes show a pronounced contrast and different contrast in the different areas (A, B, C and D) appearing in Fig. 1 (b,d) due to different crystallographic orientations of the individual grains. The bend and split of the domain marked by arrows at the grain boundary regions (shown arrows) may be attributed to the existence of inhomogeneous lattice distortions or spatial defects which destroyed the continuity of ferroelectric domains and minimized the elastic energy and depolarization fields at the grain boundaries. We believe that the observed contrast is due to the agglomerates of polar clusters. Since random fields and mechanical stresses play important roles in the formation of these agglomerates, they are expected to obey the fractal laws even in the presence of the stabilizing effect of the surface.

In the same time, the size and shape of these polar nanoregions seem random at first sight. For the quantitative data treatment we used a correlation function technique, which has been successfully used for topographic data analysis [5, 6]. The fitting gave the values of correlation length for PLZT 8/65/35 of about 160 nm and for 9.5/65/35 ~ 120 nm, respectively.

The degree of fractal branching of domain structure typically changes at the grain boundary. Two types of grain boundary have been found: with correlation and without correlation in domain structures of the neighbored grains. Continuous fractal branching from one grain to another present only for linear character of domain structure. For non correlation
domain structures in neighbored grains its character has more degree of fractal branching, especially near the grain boundary.

It is thus can be concluded that the PLZT ceramics with high concentration of La (≥8 at. %) preserve the domain contrast at the nanoscale, even if the macroscopic properties do not exhibit any ferroelectricity. Random network of maze nanopolar patterns is a direct consequence of La-induced disorder and have to be investigated as a function of temperature in order to observe the freezing of polar nanoclusters. These measurements are currently underway. It is proved that the PFM technique is well suited for the inspection of polar mesoscopic structures on the surface of relaxor ferroelectrics.

References:

Figures:

Figure 1. Topography (a, c) and piezoresponse images (b, d) of ceramics PLZT with concentrations La 8 and 9.5 %, respectively.