AFM domain patterning in structurally disordered ferroelectric crystals

T.R. Volk[1], R.V. Gainutdinov[1], Ya.V. Bodnarchuk[1], Xiaoyong Wei[2], Xin Liu[2]

[1]*Shubnikov Institute of Crystallography of FSRC "Crystallography and Photonics" RAS, Moscow, Russia*
Volk-1234@yandex.ru

[2]*Electronic Materials Research Laboratory, Key Laboratory of the Ministry of Education & International Center for Dielectric Research, Xi'an Jiaotong University, 710049, Xi'an, China*

At present, crystals of the solid solutions $Pb(Mg_{1/3}Nb_{2/3})O_3$ - $xPbTiO_3$ (PMN-xPT) are under intensive investigations due to their excellent piezoelectric characteristics. Studies in the domain engineering are of importance for an insight into contribution from the domain formation and resulting domain-wall density to the piezoelectric coefficients.

We present the results of domain writing by dc AFM-tip voltages in the tetragonal PMN-0.4PT crystals.

The application of AFM domain patterning is known to be restricted by the formation of so-called "anomalous" domains [1-3]. Recall, in the "anomalous" domains, observed for the first time in $BaTiO_3$ [1] and found later in various ferroelectrics (for refs see [3]) a small central area is polarized oppositely to the poling field. According to the currently accepted model [2, 3], this anomalous switching is caused by the charge carrier injection from the tip and subsequent formation of a space-charge field E_{sc} directed oppositely to the poling field.

We analyzed the problem of anomalous domains on the example of PMN-PT crystals [4].

Two types of domain were formed in these crystals under AFM-tip voltages. The occurring anomalous ones and "normal" (uniformly polarized along the poling field) ones are presented in Figure 1 (the upper and lower images, respectively). The domain shape is distributed randomly over the surface and is non-reproducible even for the identical exposure conditions (as exemplified by Fig. 1)

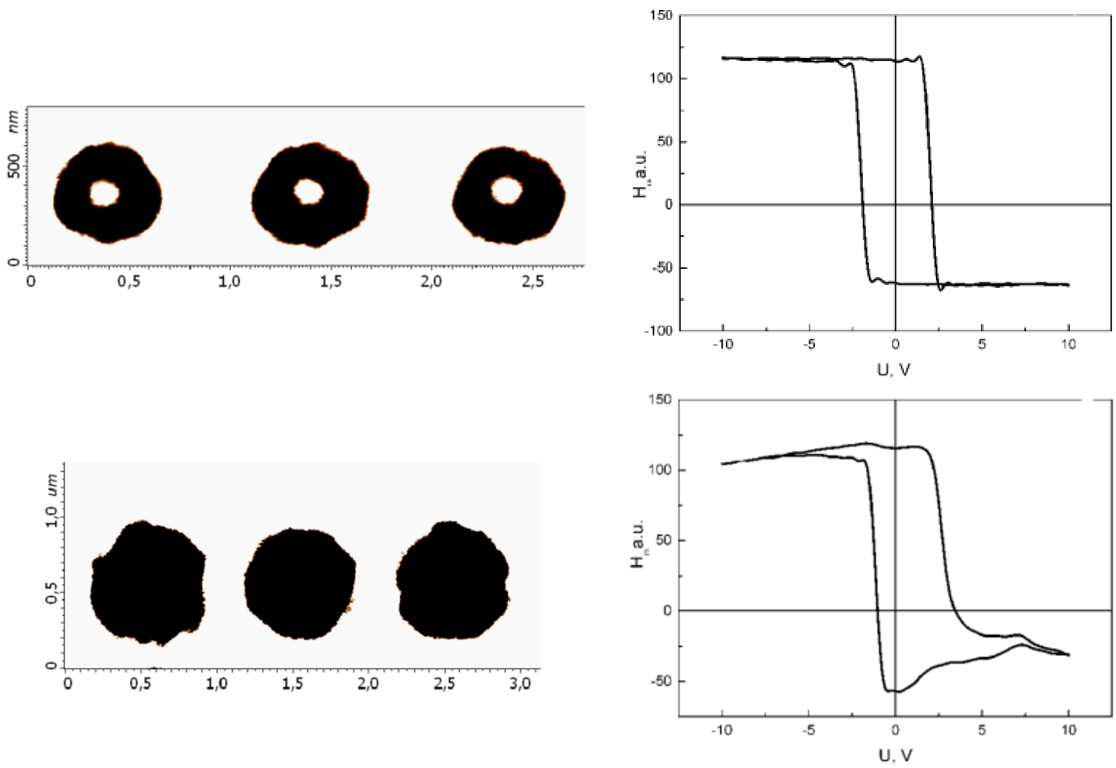

Figure 1. On the left: PFM images of the domain rows written at identical exposure conditions (U_{tip} = 50 V, t_p = 100 ms) in two closely spaced surface regions; the anomalous (upper) or normal (lower) domains arise.
On the right: the local piezoelectric hysteresis loops measured in these regions; the normal domains occur in the regions showing strongly biased loops (the higher bias voltage U_b); the anomalous domains are characteristic for the regions with lower U_b.

The domain shape was found to correlate with the local piezoelectric hysteresis loops H_ω-U_{tip}. Namely, the larger is the local bias voltage U_b, the higher is the tip voltage U_{tip} at which the anomalous domains appear. In the case that the loop is strongly biased (the lower loop), the formed domains are normal. In the framework of the injection model [2, 3] this means that the necessary condition of the anomalous domain formation is $E_{sc} > E_b$ (where E_{sc} is the local space charge field under a tip, caused by the charge injection, and E_b is the local bias field). This conclusion was confirmed in other disordered ferroelectrics.

The relaxation kinetics of anomalous domains depends on the exposure conditions; the domains written by high U_{tip} are completely stable in a qualitative agreement with the model [2, 3]. The normal domains are decaying significantly faster than the anomalous ones, the decay kinetics depending on the domain spacing

The exposure characteristics of the domain diameter D are independent of the domain shape, i.e. being identical for the normal and anomalous domains. For a given t_p, $D(U_{tip})$ is described by a unified linear function in the whole U_{tip} range. The curves $D(t_p)$ follow a power law $D \sim t_p^k$ with the exponent k very weakly varying with U_{tip}.

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