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Short Communication

Interrelation of Shape and Structure of Domain Walls with Magnetic Inhomogeneities

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By using atomic force microscopy (resolution of 40 nm) the effect of surface roughness and internal inhomogeneities on the fine structure of domain walls of different types in thin transparent orthoferrite samples cut perpendicular to the optic axis for $YFeO_3$ and axis [001] for $DyFeO_3$ has been studied.

Keywords: Domain structure, Scanning probe microscopy types of domain walls.

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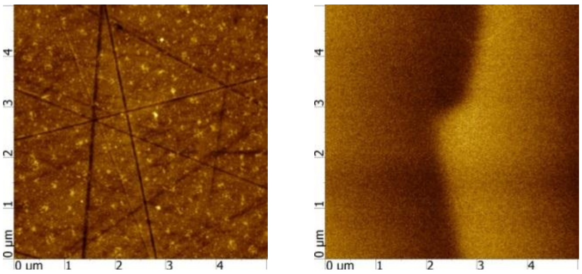
Devices for storage and processing information that utilize materials with electric and magnetic ordering increasingly find application [1]. A special place in this series is taken by orthoferrites that have four magnetic sublattices for both d-subsystem (magnetic ions Fe^{3+}), and *f*-subsystem (Y^{3+} and rare-earth ions R^{3+}). *f*-subsystem being many-electron one dictates the origination of the electric ordering. In addition to this, in certain phases a spontaneous electric polarization appears at phase transitions, induced by magnetic field, in *f*- and *d*-subsystems. Those structural features are responsible for magneto-electric interactions in $RFeO_3$. The basic mechanism of magnetization reversal in these materials is the motion of domain walls (DWs), which is of a nonlinear nature and occurs at supersonic speeds and is accompanied by the appearance of gyroscopic vortices [2] that propagate along DW.

Fig. 1 – Confocal magneto-optical image of domain structure $YFeO_3$

Domain structure (DS) and the fine structure of DW in $RFeO_3$, α-Fe_2O_3 and $FeBO_3$ were studied earlier [3, 4] by using Raman microspectral scattering. In the present paper magnetic force microscopy (MFM) has been used to investigate the way roughness of surfaces and internal inhomogeneities (grows nonmagnetic inhomogeneities) influence the fine structure of DW of various types in lamellar transparent orthoferrite samples cut perpendicular to the optic axis for $YFeO_3$ and axis [001] for $DyFeO_3$ with a space resolution of 40 nm. At the initial state DS and DW have been visualized with the modified for magneto-optic studies confocal microscope, which was a component of the microspectrometer (OmegaScope) integrated with the atomic force microscope (SmartSPM). In a uniformly magnetized lamellar sample $RFeO_3$ multi-domain structure was created (Fig. 1) with a rectangular and sinusoidal shape that had excessive free energy. It had DW of both Neel and Bloch type.

Topographic image of the surface is indicative of submicron-scale defects as tracks of mechanical polishing (Fig. 2a). The distribution of the normal component of the magnetic field gradient in the neighborhood of DW according to MFM is given in Fig. 2b. MFM made it possible to reveal on DS and DW magnetic kink-like formations that are immediately associated with these surface defects. To study these two- pass scanning technique was used combining semicontact atomic-force and magnetic-force studies.



a b

Fig. 2 – Image of a surface site of $YFeO_3$ sample in the neighborhood of DW: a – image of surface topography; b – MFM image of a kink-like bend of DW

By one-pass scanning along sinusoidal DW data about its structure within the bend head-to-head have been obtained (Fig. 3). It was established that the DW knee was made up of piecewise linear sites inked by special points (breather-like formations). This can be explained by the fact that to minimum of the free energy in orthoferrites there corresponds stripe DS. It must be noted that the DW width along the full length to the inflection point remained constant and was of the order of 2 µm. After the passage of the point of extremum its width increased to 3 µm in a jump fashion.

Interrelation between the DW orientation and crystallographic axes in $DyFeO_3$ sample whose plane was perpendicular to axis [001] was studied by MFM methods. This kind of sample orientation due to birefringence significantly reduces magneto-optic quality factor, which

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does not allow one to determine the location and shape of DW in a magneto-optic fashion. For studying this only one-pass MFM technique was used. Curvature radius (40 nm) of the cantilever probe made it possible to improve the accuracy of MFM measurements by an order of magnitude compared to optical resolution. DWs of various types were studied, which were of different shapes and width. Fig. 4a, b shows MFM images of Bloch DW and Neel DW, the formation of which is typical for such orientation of the DyFeO$_3$ sample. On the right-hand side shown is a "magnetic profile" of variation in magnetic momentum along the line perpendicular to the DW plane. From Fig. 2 it follows that the wall thickness was 3 and 0.7 μm for Bloch DW and Neel DW, respectively. In orthoferrites one-axis anisotropy plays an important role, which makes the origination of two types of DWs equally probable with orientation perpendicularly either to axis [100] (Neel) or axis [010] (Bloch), whose surface energy is determined: $\sigma^{N,B} \sim (AK_{1,2})^{1/2}$. Here σ_N and σ_B are the energy of Neel DW (at $K_1 < K_2$) and Bloch DW (at $K_2 < K_1$); A is the exchange interaction constant; K_1, K_2 are the one-axis anisotropy constants. It follows from this that for such orientation of the plate of the DyFeO$_3$ sample DW of the Bloch type is energetically more favorable: $\sigma_B < \sigma_N$.

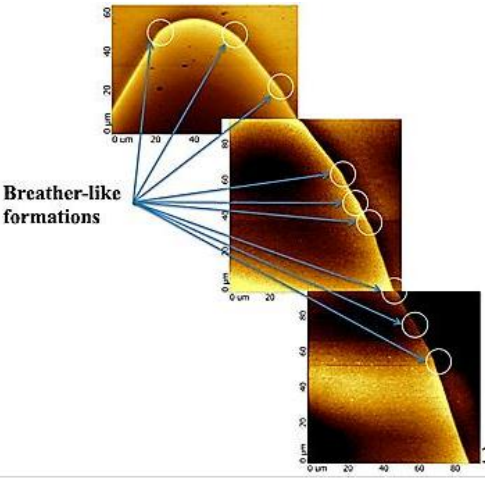

Fig. 3 – MFM image of DW within the bend region (head-to-head)

DW corresponds to the magnetized wave of the soliton-like type as it follows from the solutions of the nonlinear sine-Gordon equation that describes the motion of vector $\vec{l}$ for both DW types considering the boundary conditions. In DW of ac type (Bloch DW) the rotation of vectors $\vec{l}$ and $\overrightarrow{m}$ takes place in the plane ac, corresponding to variation of vector $\overrightarrow{m}$: $m_X = \frac{d}{\delta \mathrm{ch}[\chi_1 y]}$, $m_Y = 0$, $m_Z = -\frac{d}{\delta \mathrm{th}[\chi_1 y]}$. For DW of ab type (Neel DW) typical is the rotation of vector $\vec{l}$ in the plane ab. In this case at angles $\varphi = 0$, $\vartheta = \pi/2$ the rotation of vector $\vec{l}$ leads to the change in direction and magnitude of vector $\vec{m}$ up to a zero value at the DW center. The equations for changes in $\vec{m}$ along the Y-axis perpendicular to the DW surface: $m_X = 0$, $m_Y = 0$, $m_Z = -\frac{d\mathrm{th}[\chi_2 Y]}{\delta}$. The variations of the weak ferromagnetic moment obtained from these equations are in correlation with "magnetic profiles" derived from MFM for each DW type, corroborating the good efficiency of the technique for the analysis of the fine structure of DW and DS.

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