Surface magnetic susceptibility and relaxation of domain walls in yttrium orthoferrite

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Using a magnetooptical method, it is established that the surface magnetic susceptibility of domain walls in yttrium orthoferrite on the (001) face is several times higher than the magnetic susceptibility of walls in the bulk, while the relaxation frequency of the "additional" motion of domain walls in the layer near the surface is approximately three orders of magnitude smaller than the bulk frequency.

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It is well known that the structure of a domain wall (DW) in the region where it reaches the surface can change drastically. For example, it can become asymmetrical[1,2] if the wall separates domains with magnetization parallel to the surface of the specimen or with twisted magnetization[3] and if neighboring domains have a component of the magnetization normal to the surface. It is natural to assume that the static and dynamic characteristics of DW that determine the magnetization processes can vary in the region near the surface.

In this work, the displacement and relaxation of DW in the region where they reach the surface were studied for the first time for single crystals of yttrium orthoferrite. It is shown that for DW near the surface which emerges to the open (001) face both the amplitude of the displacement in a fixed external magnetic field and the relaxation time determined by its frequency dependence differ sharply from the corresponding bulk characteristics.

The magnetic susceptibility of the ferromagnetic specimen with strip domains, separated by 180 ° DW, can be written in the form

$$\kappa = \frac{2I_s x_0}{l\mathrm{H}} ,$$

where x_0 is the displacement of the DW in the field H, l is the width of the domain, and I_s is the saturation magnetization. Therefore, the magnetic susceptibility of a separate DW can be described by the coefficient $k = x_0/\mathbf{H}$. The displacements x_0 of a separate DW on the surface of $YFeO_3$ single crystals were measured with the help of a magnetooptical technique with micron resolution.[4]

When the slit of a FÉU is moved across the wall (x axis), a magnetooptical signal was observed only on the section of the surface remagnetized during the motion of the DW under the action of $\mathbf{H}\|C$. The half-width of the distribution curves $\delta(x)$, measured with the help of the polar Kerr effect on the (001) face and the equatorial Kerr effect on the $(1\bar{1}0)$ face, determined the amplitude of the displacement x_0 of DW from the equilibrium position.

The curves of $\delta^{\mathrm{pol}}(x)$ and $\delta^{\mathrm{eq}}(x)$, obtained on the natural faces of a $YFeO_3$ single crystal and on a single-crystal plate with a thickness of 60 μm, cut perpendicularly to the c axis, are shown in Fig. 1. The typical curves presented (there is a statistical spread $x_0 \sim 20\%$ from wall to wall and from one section to another) show that the displacement amplitudes of DW on the (001) face with $f_2 = 1258$ Hz decrease by a factor of 2–3, while on the face parallel to the c axis, the displacement amplitude of DW does not change (Fig. 1). We note that when the amplitude of the external magnetic field **H** decreases, the quantity $\delta^{\mathrm{pol}}(x)$ in the region of displacement of DW at frequency f_2 generally vanishes (see dashed curves in Fig. 1).

The curves $k(f)$, measured on a single-crystal plate and on natural faces of $YFeO_3$ (curves 1, 2, and 3, respectively), are presented in Fig. 2. The same figure presents for comparison the curve $k(f)$ (curve 4), obtained from the bulk magnetization curves of a $YFeO_3$ single crystal, measured by the induction method. It is evident that the quantity $k(f)$ for the bulk and the $(1\bar{1}0)$ face does not depend on frequency up to 7 kHz. On the other hand, the curves $k(f)$ for the (001) face represent typical relaxation spectra with relaxation frequency ~ 500 Hz. The results obtained are likewise confirmed by our integral measurements of the magnetization curves for the (001) surface of a completely illuminated single crystal. The results of the measurements are presented in curves 1 and 2 in Fig. 3. The same figure presents for comparison the bulk magnetiza-

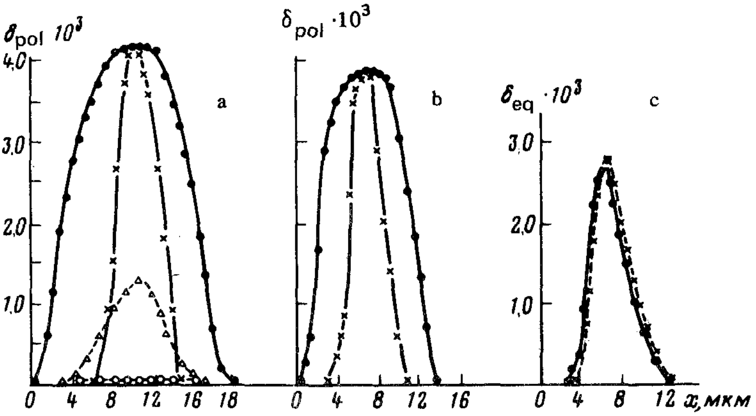

FIG. 1. Curves of the distribution $\delta(x)$, measured at ● $-f_1 = 78$ Hz, × $-f_2 = 1258$ Hz on the (001) face (a), $H = 0.28$ Oe ($\Delta - f_1$, ○ $-f_2$, H = 0.14 Oe); on a plate (b) with H = 2.1 Oe; and on the $(1\bar{1}0)$ face (c) with H = 0.46 Oe.

tion curves (3, 4) measured by the induction method. It is evident that curves 3 and 4 ($f_1 = 78$ Hz and $f_3 = 7$ kHz) are nearly identical, while curve 1 lies above curves 2, 3, and 4, which agrees with the results presented above.

Thus the experimental results indicate the fact that on the (001) face the local magnetic susceptibility of DW at the surface is approximately three times higher than the bulk susceptibility and, in this case, the "additional" displacement of DW is already "switched off" at a frequency of 1 kHz and the surface susceptibility becomes the bulk susceptibility. This indicates that the relaxation frequency of the surface magnetic susceptibility is three orders of magnitude smaller than the bulk frequency measured by Rossol.[5]

The results obtained can be explained qualitatively as follows. As is well known, the coefficient of elasticity, characterizing the force returning the DW to the equilibri-

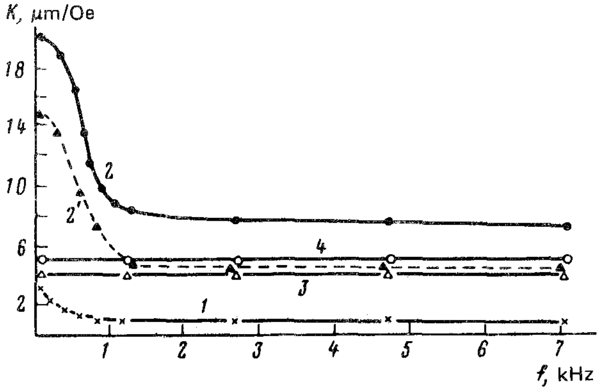

FIG. 2. Frequency dependences $K = x_0/H$: 1) plate H = 2 Oe; 2, 2′) (001) face H = 0.7 Oe; 3) (110) face H = 0.6 Oe; 4) bulk H = 0.6 Oe.

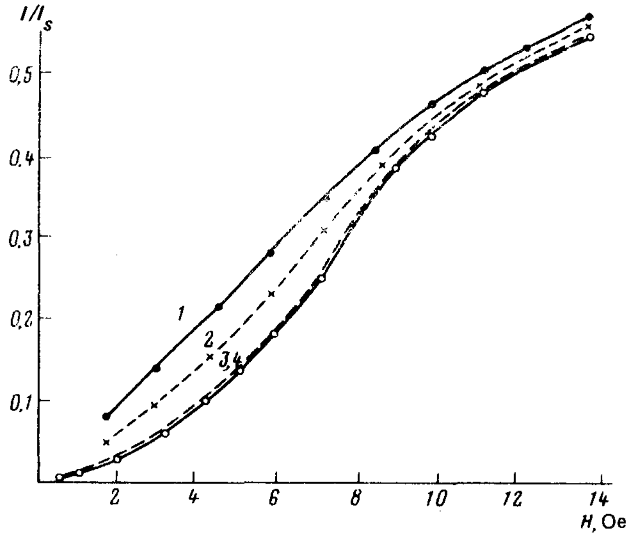

Fig. 3. Magnetization curves: 1, 2) (001) faces at $f_1 = 78$ Hz and $f_2 = 1258$ Hz, respectively; 3,4) bulk at $f_1 = 78$ Hz and $f_3 = 7$ kHz.

um position in perfect single-crystalline specimens, whose easy anisotropy axis is perpendicular to the surface, is determined primarily by the magnetostatic interaction energy, i.e., the resulting demagnetization field acting on the DW. In this case, as indicated in Ref. 6, the dissipative fields created by the dynamic charges on the surface decrease the return force acting on the wall, which leads to an increase in the displacement amplitude of DW on the surface. To obtain quantitative information on the quantity x_0, it is necessary to take into account not only the indicated change in the acting field but also the dependence of the energy density of DW on the displacement amplitude, including its bending. The observed decrease in the relaxation frequency for sections near the surface can also be understood qualitatively. It is well known, for example, that the change in the damping parameter in the Landau-Lifshitz equation for iron-yttrium garnet, determined from the DW mobility, exceeds by two orders of magnitude the value found from the width of the ferromagnetic resonance line.[6,7] This means that the effective friction forces for precessing spins in a structurally complex object such as DW increase considerably compared to the homogeneous precession in the case of ferromagnetic resonance. For this reason, the increase in the friction force observed by us can be related to a more complicated DW structure in the near-surface region, again including an increase in the energy losses due to bending oscillations.[6] At the same time, such a large increase in these forces (by three orders of magnitude) is surprising. We have therefore presented in this paper information only on observation of the polar Kerr effect on the (001) face, i.e., on the change in the normal to the surface component I in the region of DW displacement. The experimental information on the tangential components I obtained by us indicate that the structure of the entire remagnetized region near the surface changes considerably with displacement of DW. This indicates in particular that the spins located within a narrow 180° interface with characteristic width of the order of 10^{-5}–10^{-6} cm as well as the spins located in the entire contiguous remagnetized region can contribute to relaxation processes.

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