Surface structure and relaxation of domain walls in yttrium orthoferrite and in a bismuth-containing garnet

G. S. Krinchik, A. V. Shtain, and E. E. Chepurova

Moscow State University
(Submitted 12 March 1984; resubmitted 28 June 1984)
Zh. Eksp. Teor. Fiz. **87**, 2014–2023 (December 1984)

A magneto-optic method is used to study the singularities of the surface structure and of the domain-wall relaxation in yttrium orthoferrite $YFeO_3$ and in the bismuth-containing garnet $(Y_2Bi)(Fe_{3.9}Ga_{1.1})O_{12}$. It is established that the surface magnetic susceptibility of the domain walls of the yttrium orthoferrite on the (001) face is several times larger than the magnetic susceptibility of the walls in the bulk, and the relaxation frequency of the "additional" advance of the domain walls in the surface layer is smaller by at least three orders than in the bulk. It is shown that the observed low-frequency relaxation of the domain walls is accompanied by dynamic rearrangement of the near-surface structure of the domain walls. An influence of an external static magnetic field on the surface structure of the domain walls is observed. Experimental proof is obtained, for the first time, of the existence of "twisted" domain walls in an iron garnet film, with a twist angle close to 90°, meaning that I_s has a Néel orientation in a domain wall on the surface.

INTRODUCTION

It is becoming now more and more obvious that the structure of domain walls (DW) in ferromagnets differs substantially from the idealized one-dimensional model proposed for an unbounded medium. Allowance for the finite dimensions of the ferromagnets, as well as for the demagnetizing fields produced on the free surfaces of the sample, leads to two- and three-dimensional DW models with concomitant vertical and horizontal Bloch lines. Resorting to multidimensional DW models made it possible to explain a number of experimental facts, such as the decrease of the DW mobility, the increase of its effective mass and of its maximum velocity, the continued motion of the DW after turning off the magnetic field (the ballistic-action effect), and others. It was shown[1,2] in particular that the presence of demagnetizing fields alters substantially both the static structure of the DW and their dynamic properties. Thus, the stray fields in samples with an easy axis perpendicular to the sample surface act on a Bloch DW in such a way that a Néel component of magnetization (perpendicular to the DW plane) appears in the DW near the surface. Such a DW is called "twisted." The existence of a twisted DW was experimentally proved by electron microscopy in investigations of a cobalt foil.[3]

It is also known that if a DW separates domains with magnetization parallel to the surface, it becomes asymmetric on emerging to the surface because of the influence of the demagnetizing field of the DW itself, and breaks up into subdomains.[4,5] Walls of this type are characterized by the presence of vertical Bloch lines, the existence of which in bubble domains was experimentally proved by a magneto-optic procedure in Refs. 6 and 7 and by electron microscopy in Ref. 8.

A direct experimental study of the near-surface static and dynamic DW properties which, as stated above, can differ from those in the bulk, is undoubtedly of interest and is the subject of the present paper. We have investigated, for the first time, using a magneto-optic procedure with micron resolution, the structure of the transition layer between domains, and the displacement and relaxation of DW in the region of their emergence to the surface of single-crystal $YFeO_3$ and of epitaxial $(Y_2Bi)(Fe_{3,9}Ga_{1,1})O^{12}$ films.

§1. MEASUREMENT METHOD AND SAMPLES

The measurements were made with upgraded magneto-optic micron-resolution apparatus whose operating principle is described in Ref. 2. As the photomultiplier slit is scanned in the image plane of an MIM reflecting microscope, the magneto-optic signal is picked off a sample surface section whose area is determined by the dimension of the indicated slit with allowance for the microscope magnification. The minimum slit size corresponds to the optical resolution D of the microscope. The use of immersion lenses and of visible light makes it possible to obtain $D = 0.3\ \mu m$. We note that a theoretical analysis of the capabilities of the dynamic magneto-optic procedure was analyzed in Ref. 9. It was shown that this procedure can yield information on the sizes and on the effective magnetization of objects much smaller than the optic-resolution limit.

An external alternating magnetic field of sufficiently low amplitude (within the reversible displacement of the DW), applied parallel to the easy axis of the investigated sample, causes the DW to oscillate about an equilibrium position. In this case the magneto-optic signal δ differs from zero only in the region of the DW displacement. The magnitude of the signal is evidence of a magnetization change due either to the alternating entry of neighboring domains into the photomultiplier slit (the domain effect) or to the motion of the DW itself, or else, more accurately speaking, to the change of the magnetization in the region where the DW emerges to the sample surface (the DW effect).

The magneto-optic effect was measured at both the first

 0038-5646/84/121161-06$04.00

(f) and second ($2f$) harmonics of the magnetization-reversal field.

To observe the magneto-optic signal from the wall, the domain effect must be excluded. This can be done by changing the incidence angle, the orientation of the incidence plane, and the polarization of the incident light, as well as by analyzing the form of the $\delta(x)$ curves. It can be shown that the distribution curve of the first-harmonic magneto-optic signal corresponding to the DW effect should reverse sign on going through the DW equilibrium position, since the plot of the distribution of the domain effect should be symmetric. At the second harmonic, conversely, the alternating-sign antisymmetric curve should correspond to the domain effect, and the magneto-optic signal from the DW should be symmetric.

In measurements at the first harmonic the amplitude of the displacement of the DW from the equilibrium position is determined either by the half-width of the domain-effect distribution curve or by half the distance between the neighboring peaks of the alternating-sign curve.[4] Similar estimates of the DW-displacement amplitude can be obtained from measurements made at the frequency $2f$, in which case it is necessary to introduce a correction factor $3\pi/4$ corresponding to the difference between the Fourier coefficients of the first and second harmonics.

To monitor the position of the DW relative to the photomultiplier slit and the light-incidence plane, an additional source of polarized light was provided and used to observe visually DW in transparent plates. The state of the domain structure in bulky samples was monitored by the powder method.

The investigations were carried out on natural faces of a single crystal and of thin single-crystal $YFeO_3$ plates. The yttrium-orthoferrite single crystal was produced by the hydrothermal method at the Crystallography Institute of the USSR Academy of Sciences.[10] The single-crystal plates, 60–70 μm thick, were cut perpendicular to the c axis from a single-crystal rod obtained by zone melting.[11] The plates were polished mechanically and chemically by the procedure described in Ref. 12. Also investigated were epitaxial $(Y_2Bi)\, Fe_{3,9}\, Ga_{1,1}\, O_{12}$ films about 6 μm thick, grown in an SmGaGd-garnet substrate.

§2. RESULTS AND DISCUSSION

The magnetic susceptibility of a ferromagnetic sample with stripe domains separated by 180° DW can be expressed in the form

$$\varkappa = 2\mathbf{I}_s x_0 / dH,$$

where x_0 is the displacement of the DW in a field H, d is the domain width, and $\mathbf{I}_s$ is the saturation magnetization. The magnetic susceptibility of an individual DW can therefore be characterized by a coefficient $k = x_0/H$, and the surface magnetic susceptibility of an individual DW by a coefficient $k^s = x_0^s/H$, where x_0^s is the amplitude of the DW displacement in the surface layer of a crystal in a field H.

The measurements were initially performed on a single-crystal $YFeO_3$ plate having a labyrinth domain structure, as well as on natural (001) and $(1\bar{1}0)$ faces of a $YFeO_3$ single crystal.[14] The distribution curves of the domain effect on the (001) face were measured with the aid of the polar Kerr effect $\delta^n(x)$ by scanning the photomultiplier slit in the direction of the DW motion (the x axis). The equatorial Kerr effect $\delta^e(x)$ was used for the $(1\bar{1}0)$ face. The entry slit of the photomultiplier corresponded to the illuminated section of the sample surface in the form of a narrow stripe parallel to the DW and measuring 0.35×3 μm. Analysis of the $k^s(f)$ plots and their comparison with $k(f)$ obtained from the bulk magnetization curves of the $YFeO_3$ single crystal, measured for the same sample by the induction method, as well as comparison of the results of the integral measurements of the magnetization of the fully illuminated (001) surface of crystal with the bulk magnetization curves, led to the following conclusions. The values of $k(f)$ in the bulk and of $k^s(f)$ on the $(1\bar{1}0)$ surface are independent of frequency up to 7 kHz. On the (001) surface, the local magnetic susceptibility of the DW at the surface is 2–3 times larger than in the bulk, and the $k^s(f)$ dependences are typical relaxation spectra with relaxation frequency $\sim$600 Hz. The "additional" displacement of the DW is "turned off" at 1 kHz. Starting with this frequency, the surface magnetic susceptibility becomes close to that in the bulk. This means that the relaxation frequency $f^s_{\rm rel}$ of the surface susceptibility of the DW in yttrium-orthoferrite single crystals is smaller by three orders than the bulk value measured by Rossol[15] and by Velikov *et al.*[16] It must be emphasized that low-frequency relaxation of the surface magnetic susceptibility was observed only on the (001) face of the $YFeO_3$ single crystal, which is perpendicular to the easy-magnetization axis, and was not observed on the (110) face. The result can therefore not be attributed to the magnetic aftereffects, as was done in Ref. 16, where the dynamics of small oscillations of DW were investigated in iron-garnet films, the more so since no low-frequency relaxation of the bulk magnetic susceptibility of DW was observed in Ref. 16 in yttrium orthoferrite.

The succeeding magneto-optic investigations were aimed at a study of the dynamic structure of a DW as it emerges to the surface [(001) face] of the sample. The magneto-optic signal, proportional to the average DW magnetization, was measured as a function of the frequency and amplitude of the external magnetic field. Visual observation of the DW in $YFeO_3$ plates made it possible to align the DW with the photomultiplier slit and with light-incidence plane accurate to within 2°. This made it possible to obtain a magneto-optic signal from the DW at small oscillation amplitudes of the order of 1–2 μm.

It is known that antisymmetric Dzyaloshinskiĭ exchange produces in orthoferrites special types of DW.[17,18] In walls of one type the antiferromagnetism vector $\mathbf{l}$ rotates in the (ac) plane of the crystal, and the resultant magnetization $\mathbf{m}$ does not change significantly when $\mathbf{l}$ is rotated but rotates likewise in the (ac) plane (DW type with rotation of $\mathbf{m}$). In walls of another type the vector $\mathbf{l}$ rotates in the (ab) or (bc) plane of the crystal, but the vector $\mathbf{m}$ remains parallel to the c axis and varies monotonically in magnitude between $+m$ and $-m$. It becomes equal to zero and reverses direction at the center of the transition layer (DW type without rotation of $\mathbf{m}$). It has been established[19,20] that at room temperature

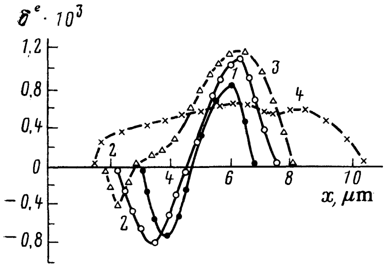

FIG. 1. Distribution curves $\delta^e(x) \sim \mathbf{I}_N$ ($f_1 = 78$ Hz) measured in a $YFeO_3$ plate: curve 1—$H = 0.7$ Oe, 2—1.4 Oe, 3—2.1 Oe, 4—4.5 Oe.

the DW produced in orthoferrites are as a rule of the first type. It was shown moreover that the domain structure is labyrinth-like and the DW can be oriented at arbitrary angles relative to the (ac) and (bc) crystallographic planes. In this case $\mathbf{l}$ and $\mathbf{m}$ always remain in the (ac) plane, forming a DW of intermediate type and of more general form than the Bloch or Néel walls. It must thus be borne in mind that when the DW were parallel or perpendicular to the light-incidence plane we measured respectively an equatorial Kerr effect δ^e proportional to a DW average magnetization perpendicular to the plane of the wall (Néel component $\mathbf{I}_N$) or parallel to the DW (Bloch component $\mathbf{I}_B$).

On going from wall to wall and from one equivalent section of the DW to another, the amplitudes x_0^s differed by no more than 20%. After prolonged measurements in weak alternating fields, however, magnetic "aging" of the sample was observed, viz., a systematic decrease of the amplitude x_0^s, but the described singularities of the surface magnetic susceptibility of the DW were preserved.

Figure 1 shows typical distribution plots $\delta^e(x) \sim \mathbf{I}_N$ obtained for $YFeO_3$ plates. Curves 1, 2, 3, and 4 were measured at various amplitudes of the external magnetic field. It can be seen that $\delta^e(x)$ acquires an asymmetric shape in a field $H = 2.1$ Oe (curve 3) and the shape of the domain effect in a field $H = 4.5$ Oe (curve 4). At the same time, when the oscillation amplitude decreases to 1–2 μm ($H < 1.4$ Oe) the $\delta^e(x)$ plots are alternating-sign antisymmetric curves (1,2). Similar curves were obtained by measuring $\delta^e(x) \sim \mathbf{I}_B$ as well as by measuring $\delta^e(x) \sim \mathbf{I}_N$ and $\mathbf{I}_B$ on the (001) face of an $YFeO_3$ single crystal.

Plots of $\delta^e(x)$ vs the frequency of the external magnetic field are shown in Fig. 2. Curves 1 and 2 correspond to $\delta^e(x)$ at $f_1 = 78$ Hz and $f_2 = 1258$ Hz. In the upper right corner of the figure are shown the frequency dependences of the maximum values of $\delta^e(x)$ for these curves. The function $\delta^n_{\max}(f)$ measured on the same section of the DW is also shown for comparison. It can be seen that $\delta^n_{\max}$ is independent of frequency at the chosen regime of DW oscillation about the equilibrium position, whereas $\delta^e_{\max}$ decreases with increasing f in the same field. In addition, the shape of the $e(x)$ plot changes somewhat at $f_2 = 1258$ Hz. The change of $\delta^e(x)$ with increasing H [the appearance of symmetric distribution curves of the magneto-optic signal from the DW (see Fig. 1)], as well as the determined change of $\delta^e(x)$ with increasing f and the decrease of $\delta^e_{\max}$, attests to a complicated dynamic restructuring of the surface layer between neighboring do-

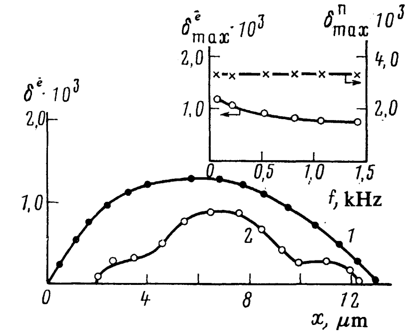

FIG. 2. Distribution curves $\delta^e(x)$ measured in a $YFeO_3$ plate in a field $H = 5.4$ Oe: curve 1—$f_1 = 78$ Hz, 2—$f_2 = 1258$ Hz.

mains with increasing DW velocity. This fact is confirmed also by the dependences of the domain effect $\delta^n(x)$ with increasing external magnetic field. Figure 3 shows the $\delta^n(x)$ distributions measured at the first (f) and second ($2f$) harmonics of the magnetization-reversal signal ($f = 78$ Hz). It can be seen that in this case the dynamic restructuring of the DW manifests itself in the appearance of steps on the $\delta^n(x)$ plots (curve 2, first harmonic), and of additional peaks (curve 4, second harmonic), compared with the $\delta^n(x)$ curves at $H = 2.1$ Oe. We note one other observation that offers indirect evidence, in our opinion, in favor of the dynamic restructuring of the domain wall. The distributions $\delta^e(x) \sim \mathbf{I}_N$ were measured with a constant magnetic field ($H_\tau = \pm 100$ Oe) applied to the crystal perpendicular to the DW. The measurement results are shown in Fig. 4. A strong influence of H on the $\delta^e(x)$ distribution is observed.

On the whole, the experimental results attest to an utterly unexpected and peculiar behavior of the yttrium-orthoferrite DW in the surface region as they emerge to the (001) face. This peculiarity is manifest by the following three features: 1) a substantial dynamic restructuring of the DW is observed, 2) the effective relaxational characteristic of the DW displacement on the surface is more than 10^3 times larg-

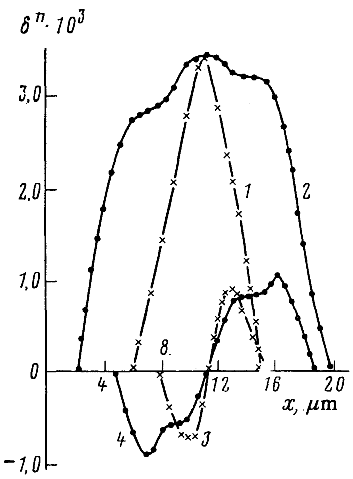

FIG. 3. Plots of $\delta^n(x)$ measured at the first (curves 1, 2) and second (curves 3, 4) harmonics of the magnetization-reversal signal: curves 1, 3—$H = 2.1$ Oe; curves 2, 4—$H = 5.4$ Oe.

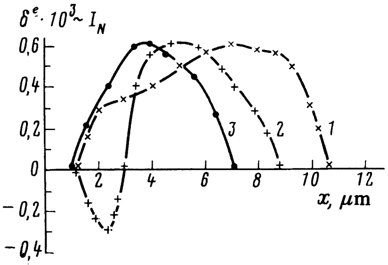

FIG. 4. Distribution curves $\delta^e(x) \sim I_N$ ($H = 4.5$ Oe) measured in a constant tangential magnetic field perpendicular to the domain-wall plane; curve 1—$H_\tau = 0$ Oe, 2— -100 Oe; 3— $+100$ Oe.

er than in the bulk, i.e., it can be said that a surface super-relaxation of the DW is observed, 3) the amplitude of the DW displacement on the DW is approximately two or three times larger than in the bulk. We shall attempt to explain qualitatively from a single viewpoint these peculiarities on the basis of contemporary premises concerning the structure and dynamic properties of DW in magnetic crystals. We shall have to use frequently analogies with iron-garnet films, whose DW properties have been investigated in greater detail in view of their extensive practical applications.

The dynamic restructuring of the DW may explain the changes observed in the shapes of curves 3 and 4 of Fig. 1 when the DW oscillation amplitude is observed. The point is that a moving DW must be accompanied by a dynamic magnetization component perpendicular to its plane.[21,22] Moreover, this dynamic transverse component serves as the prime source of the motion, the cause of its having an effective mass, etc. The qualitative difference between the dynamic and static transverse components is that the former reverses sign as a function of the direction of the DW motion. It is therefore clear that the assumption that the role of dynamic transverse component of the magnetization increases with increasing oscillation amplitude, and hence with increasing DW velocity, can explain the change in the shape of the curves in Fig. 1. The shape of the $\delta(x)$ curve for the dynamic component of the DW magnetization should be the same as that of $\delta(x)$ for the domain effect. This can be explained in the following manner. Let the photomultiplier slit be located at the equilibrium position $x = 0$ of the DW. The magneto-optic effect produced by the static transverse component and recorded at the first harmonic should then be zero, since the DW arrives at this point in an unchanged state. On the other hand the effect of the dynamic component is a maximum, since this component reverses polarity in the course of the motion. It is the superposition of this last effect that leads initially to the asymmetry of the summary $\delta^e(x)$ curve, and next also to the "domain" curve 4.[1)] From this viewpoint, the difference between the $\delta^e(x)$ in Fig. 4 becomes understandable. The constant tangential magnetic field apparently changes the static component of the DW magnetization (increasing and decreasing it respectively at $H_\tau = \mp 100$ Oe), and this leads to a change of the $e(x)$ distribution. In particular, at $H = -100$ Oe the $\delta^e(x)$ curve acquires an antisymmetric shape corresponding to the DW magneto–optic signal which is proportional to the static component of the DW and is recorded at small amplitudes of its oscillation (see curve 1 of Fig. 1). Incidentally, the fact that a relatively small tangential magnetic field influences the DW structure is evidence that when the factors that cause asymmetry of the DW structure in the surface region are considered, account must be taken of the magnetostatic field of the neighboring domains; the latter equals $8\mathbf{I}_s$ according to Ref. 22, i.e., ~ 80 Oe for $YFeO_3$.

The notion of a substantial change in the near-surface DW structure, which leads to formation of a dynamic horizontal Bloch line, provides a likely explanation of the observed super-relaxation of the surface section of the DW. Theoretical calculations[23] confirmed by experiments on iron-garnet films[24] show that if a DW is "packed" densely enough with Bloch lines, it becomes very "rigid" and its mobility μ decreases precipitously; μ is the coefficient that relates the DW velocity with magnetic field intensity:

$$\mu = \gamma \Delta_0 / \alpha, \tag{1}$$

where γ is the gyromagnetic ratio, α is the dimensionless damping parameter in the Landau-Lifshitz equation, and $\Delta_0 = (A/K)^{1/2}$ is the relative width of the DW (see, e.g., Ref. 25). The change of mobility compared with a normal DW is proportional to α^2. For yttrium-iron garnet, the parameter α determined from the FMR line width is 10^{-4}. Consequently, the indicated change of the internal structure of the DW can lower its mobility by a factor 10^8. Yttrium orthoferrite is likewise a ferromagnet characterized by a small damping parameter α, since it is a ferrodielectric with Fe^{3+} ions. It is clear from the foregoing that, generally speaking, the mechanism described can effect the required mobility decrease of the surface section of the DW in yttrium orthoferrite. We note also that the fact that the DW has a section that brakes its motion so strongly should influence also the dynamic properties of the DW as a whole, and this influence should depend naturally on the sample thickness, on the relative DW fraction that emerges to the (001) surface, and others. It is possible that this circumstance is the cause of the large scatter of the DW mobilities obtained for $YFeO_3$ by different workers.[15,26,27] Thus, Ref. 15 cites for $YFeO_3$ the values $f_{rel} = \omega/2\pi \sim 600$ kHz and $\mu \sim 900$ cm/s · Oe ($T = 295$ K), corresponding to $\alpha = 1.06 \cdot 10^{-2}$. The indicated value of μ is 4 − 5 times smaller than those measured in Ref. 16 and 8–10 times smaller than obtained in Ref. 27 by the Sixtus-Tonks method. Moreover, the value $\mu \sim 40\,000$ cm/s · Oe obtained in Ref. 27 for DW moving along c corresponds to $\alpha \sim 10^{-4}$. We express the resultant damping constant as a sum of the damping constants of two mechanisms:

$$\alpha' = \alpha + p/h, \tag{2}$$

where α is the damping constant of a normal DW and p/h is the contribution of the surface damping and is inversely proportional to the plate thickness h; in this case

$$\mu = \gamma \Delta_0 / (\alpha + p/h), \tag{3}$$

$\mu \approx \gamma \Delta_0 h/p$ and $\mu \approx \gamma \Delta_0/\alpha$ as $h \to 0$ and $h \to \infty$, respectively. Assuming that in the experiments of Ref. 27 the mobility μ_c of the samples cut along c was determined by α, we can find p by using the value of μ obtained for a DW moving along the **a**

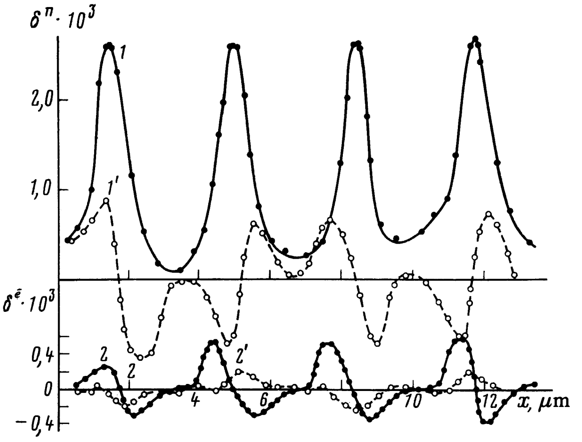

FIG. 5. Plots of $\delta^n(x)$ (curve 1) and $\delta^e(x) \sim \mathbf{I}_N$ (curve 2), measured with the photomultiplier slit scanned perpendicular to the stripe domains of a $(Y_2Bi)(Fe_{3,9}Ga_{1,1})O_{12}$ garnet film ($H = 8.4$ Oe, $f = 78$ Hz); $\delta^n(x)$ (curve 1') and $\delta^e(x)$ (curve 2') measured at the second ($2f$) harmonic of the magnetization-reversal signal ($H = 14$ Oe).

or **b** axis. It was found that $p \sim 0.7\,\mu$m. The mobility estimate from (3) at $h = 60\,\mu$m yields $\mu \sim 850$ cm/s · Oe, which agrees well with Rossol's data.[15] We can estimate from (3) the effective thickness of the surface layer that participates in the observed low-frequency surface relaxation. It was found to be of the order of 0.4 μm.

Finally, the dynamic restructuring of a DW near the surface may be the cause of its "additional" advance on the surface compared with the bulk. The point is that one of the most interesting manifestations of the dynamic internal restructuring of a DW in an iron garnet is the ballistic aftereffect or "overshoot" of the wall, which manifests itself in further motion of the DW after the driving magnetic pulse has stopped. This additional advance is comparable with the main motion.[22,25] The physical explanation of the ballistic aftereffect is the following: in the course of the initial motion the internal structure of the wall is changed. Becoming twisted, the wall stores additional energy that is later recovered, on untwisting, in the form of the additional advance. One cannot exclude even a possible manifestation of the ballistic aftereffect in the surface region, for in this case the dynamic internal restructuring of the DW occurs precisely in this region.

We dwell now on the magneto-optic investigations of the structure of a DW emerging to the surface of a $(Y_2Bi)(Fe_{3,9}Ga_{1,1})O_{12}$ garnet film. Our measurements of the frequency dependence of the surface magnetic susceptibility of DW in films of this iron garnet have shown that $k^s = x_0^s/H$ remains practically constant at frequencies up to 7 kHz. This is apparently due to the small α of this material, and does not preclude the possibility of observing low-frequency relaxation of the magnetic susceptibility at higher frequencies. It can be noted, however, that on increasing the amplitude of the DW oscillations we observed a substantial change in the shape of the $\delta(x)$ distribution curves. We can consequently surmise also a dynamic restructuring of the DW in the surface region of garnets.

The results of magneto-optic investigation of the DW structure of the indicated garnet films are shown in Fig. 5. Curve 1 reflects the distribution of the domain effect measured with the aid of the polar Kerr effect at the first harmonic of the magnetization reversal signal. The peaks of this curve coincide with the regions of the DW displacements. The half-width of each peak determines the amplitude x_0^s of the DW oscillation. It can be seen that $2x_0^s \approx 0.9\,\mu$m in a field $H = 8.4$ Oe. The distance between peaks corresponds to a stripe-domain width $d \approx 3.4\,\mu$m, which agrees with the data obtained by using the Faraday effect. Curve 2 reflects the function $\delta^e(x)$, which is proportional to the Néel component of the DW magnetization. The zeros of δ^e correspond to the domain sections whose magnetization is not reversed, and the two peaks of opposite sign correspond to the magneto-optic signal from the DW. The distance between these peaks determines also the amplitude of the DW oscillation. According to the analysis of the shapes of the signals from the DW, the form of curve 2 corresponds to the situation wherein the Néel component of the magnetization is oppositely directed, i.e., the orientations of the Néel sections of the DW on the surface are determined by the direction of the transverse magnetostatic field of the surface magnetic charges. Measurement of the distribution of $\delta^e(x)$, which is proportional to $\mathbf{I}_B$, has shown that on the sample surface this component is lower than $\mathbf{I}_N$ by at least an order of magnitude.

The dashed curves 1' and 2' in the same figure show the $\delta^n(x)$ and $\delta^e(x)$ dependences measured at the second harmonic of the magnetization-reversal signal. It can be seen that the shape of curve 2', characterized by a sign reversal of the DW magneto-optic signal, confirms the foregoing conclusion that the magnetization direction is reversed in neighboring DW. It was observed in addition that the domain magneto-optic signal at the second harmonic is sensitive to the orientation of the domain magnetization. Curve 1' is of alternating sign, but in contrast to the magneto-optic DW signal at the first harmonic (curve 2) the domain effect for the neighboring walls is shifted 180° in phase, indicating in fact that the nearest DW move in antiphase. The use of the indicated procedure permits thus a reliable determination of the magnetization directions in a domain and in a domain wall.

On the whole, the data obtained are evidence that the DW magnetization on the surface of the investigated $(Y_2Bi)(Fe_{3,9}Ga_{1,1})O_{12}$ garnet films is determined mainly by the Néel component, so that the DW is twisted. The twist angle is close to 90° and determines the Néel orientation of the vector $\mathbf{I}_s$ at the center of the wall on the surface relative to the Bloch orientation in the volume of the film.

In conclusion, the authors thank A. Ya. Zalesskiĭ for supplying the yttrium orthoferrite crystal for the measurements and A. Ya. Chervonenkis for growing the bismuth-containing garnet films.

[1)] We note that an asymmetry of the $\delta(x)$ curves for 180° domain walls in iron was observed when the oscillation amplitude was increased and was similarly explained in Ref. 4.

[1]J. C. Slonczewski, AIP Conf. Proc. **5**, 170 (1972).
[2]E. Schlömann, Appl. Phys. Lett. **21**, 227 (1972).
[3]T. Suxzuki and M. Takahashi, Japan J. Appl. Phys. **17**, 1371 (1978).
[4]G. S. Krinchik and O. M. Benidze, Zh. Eksp. Teor. Fiz. **67**, 2180 (1974)

[Sov. Phys. JETP **40**, 1081 (1975)].
[5]A. Hubert, Teorie der Domänenwändein geordneten Medien, Springer, 1974.
[6]L. M. Dedukh, V. I. Nikitenko, A. A. Polyanskiĭ, and L. S. Uspenskaya, Pis'ma Zh. Eksp. Teor. Fiz. **26**, 452 (1977) [JETP Lett. **26**, 324 (1977)].
[7]M. Labrume, M. Miltat, and M. Kleman, J. Appl. Phys. **49**, 2013 (1978).
[8]P. I. Grundy, Phys. Stat. Sol. (a) **20**, 295 (1973).
[9]V. E. Zubov and G. S. Krinchik, Fiz. Tverd. Tela (Leningrad) **21**, 2816 (1979) [Sov. Phys. Solid State **21**, 1622 (1979)].
[10]A. V. Zalesskiĭ, A. N. Lobachev, L. N. Dem'yanets, *et al.*, Zh. Eksp. Teor. Fiz. **61**, 2337 (1971) [Sov. Phys. JETP **34**, 1252 (1972)].
[11]A. M. Balbashov *et al.*, Izv. AN SSSR **35**, 1243 (1971).
[12]I. Basterfield, J. Phys. **D2**, 1159 (1969).
[13]A. M. Balbashov *et al.*, Izv. AN SSSR, Ser. Fiz. **38**, 2421 (1974).
[14]G. S. Krinchik, E. E. Chepurova, and A. V. Shtain, Pis'ma Zh. Eksp. Teor. Fiz. **37**, 362 (1983) [JETP Lett. **37**, 427 (1983)].
[15]F. C. Rossol, J. Appl. Phys. **40**, 1082 (1969).
[16]L. V. Velikov, E. L. Lyashchenko, and S. S. Markianov, Zh. Eksp. Teor. Fiz. **84**, 783 (1983) [Sov. Phys. JETP **57**, (1983)].
[17]L. N. Bulaevskiĭ and V. L. Ginzburg, Pis'ma Zh. Eksp. Teor. Fiz. **11**, 404 (1970) [JETP Lett. **11**, 272 (1970)].
[18]M. N. Farztdinov and S. D. Mal'ginova, Fiz. Tverd. Tela (Leningrad) **12**, 2955 (1970) [Sov. Phys. Solid State **12**, 2385 (1971)].
[19]A. K. Zvezdin, Pis'ma Zh. Eksp. Teor. Fiz. **19**, 98 (1974) [JETP Lett. **19**, 60 (1974)]; Zh. Eksp. Teor. Fiz. **68**, 1434 (1975) [Sov. Phys. JETP **41**, 715 (1975)].
[20]A. V. Zalesskiĭ, A. V. Savvinov, I. S. Zheludev, and A. K. Ivashchenko, Zh. Eksp. Teor. Fiz. **68**, 1449 (1975) [Sov. Phys. JETP **41**, 723 (1975)].
[21]V. G. Bar'yakhtar, B. A. Ivanov, and A. A. Sukstanskiĭ, ibid. **78**, 1509 (1980) [Sov. Phys. JETP **51**, 757 (1980)].
[22]T. O'Dell, Ferromagnetodynamics (Russ. transl.), Mir, 1983.
[23]J. C. Slonczewski, AIP Conf. Proc. **5**, 170 (1972); J. Appl. Phys. **44**, 1759 (1973).
[24]A. P. Malozemoff and J. C. Slonczewski, Phys. Rev. Lett. **29**, 952 (1972).
[25]A. P. Malozemoff and J. C. Slonczewski, Magnetic Domain Walls in Bubble Materials, Academic, 1979.
[26]P. W. Shumate, J. Appl. Phys. **42**, 5770 (1971).
[28]C. H. Tsang, R. L. White, and R. M. White, J. Appl. Phys. **49**, 6052 (1978); AIP Conf. Proc. **29**, 552 (1975).

Translated by J. G. Adashko