Motion of Bloch walls in a 180-degree domain wall under the action of gyrotropic forces

V. S. Gornakov, L. M. Dedukh, and V. I. Nikitenko

Institute of Solid State Physics, USSR Academy of Sciences
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A magneto-optic method is used to investigate the influence of an external magnetic field (H_y), acting perpendicular to 180-degree domain walls in an yttrium iron garnet, on the characteristics of the forced and free oscillations and of the drift of Bloch lines (BL) due to the gyrotropic forces produced when the domain walls oscillate in a field (H_x) parallel to the magnetization vectors in the domains. The Fourier expansion of the optical signals that represent the motion of the BL as they oscillate about equilibrium or drift positions is studied. The amplitude and phase of the BL oscillations are found to depend on the magnitude and polarity of H_y. It is shown that the BL effective mass and the viscous-friction coefficient, calculated from the experimental data, agree for a definite range of fields H_y with the theoretical estimates. The BL drift velocity and direction in an above-critical sinusoidal field H_x is found to depend on the magnitude and polarity of H_y. The results are discussed on the basis of the assumption that the BL contain Bloch points that are moved by the field H_y.

The last decade has seen persistent expansion and progress of research into the properties of Bloch lines (BL), which not only influence the quality of the existing bubble-domain computer memories,[1] but act as information carriers in already developed new magnetic-memory elements with ultrahigh storage density.[2] Bloch lines are produced in a domain wall that is broken up into "subdomains" with opposite spin rotation (Fig. 1), and exert a decisive influence on the character of motion of the entire wall. Being transition sections between subdomains in the wall and simultaneously between adjacent domains, a BL is characterized by a vortexlike distribution of the spins and by ensuing specific processes.[3] They are manifest, in particular, by the fact that simultaneously with their motion with the domain walls they move also along the wall under the influence of gyrotropic forces. Moreover, they cause a displacement of the domain wall itself if the external magnetic field (H_z in Fig. 1) does not exert on it a direct pressure, but only stimulates motion of Bloch lines along the wall.[4]

Direct experimental investigations[4,5] of BL motion along elliptic trajectories under the influence of gyrotropic forces in an yttrium iron garnet (YIG) placed in an oscillating magnetic field have made it possible to determine the components of the effective mass (m) and the coefficients of viscous friction (β), which characterize the BL motion along a 180-degree wall (m_x and β_x) and in a direction normal to it (m_y and β_y). The values obtained for m_x and m_y agreed quite well with the theoretical estimates, while the discrepancies between β_x and β_y did not exceed an order of magnitude. Direct experiments[6] led, moreover, to observation of an unusual BL drift in stronger alternating fields, a drift unexplained to this day.

One of the causes of the noted disparity may be that the theoretical analysis of Ref. 5 was based on consideration of monopolar BL, whereas under real conditions the latter can contain also the so-called Bloch points.[1] Their presence should first of all decrease substantially the total gyrotropic force acting on the BL, and as a consequence lead to an apparent increase of the measured viscosity for the BL motion.

The actual spin distribution in BL may also be the cause of their drift in an oscillating magnetic field.[6] Iordanskiĭ and Marchenko[7] have shown theoretically that under conditions of nonlinear BL oscillations the BL can be acted upon by a certain constant force bringing about the unidirectional displacement, observed in Ref. 6, of all the BL in the domain wall. The sign of this force depends on the direction of the spin rotation in the BL.

It is important to note, finally, that the theory of Refs. 1 and 5 was developed in a linear approximation, whereas experiment revealed a number of nonlinear peculiarities of the BL motion. They were manifested not only in the BL drift observed in above-critical fields,[6] but also in the shapes of the plots of the resonant displacements of the BL, as well as in the dependence of the resonance frequency on the field amplitude.[4] Analysis of the conditions of the BL motion has shown,[5] in addition, that the alternating force acting on the BL in the direction in which its displacement was measured had a complicated dependence on the characteristics of the external magnetic field. In particular, the force produced by the external magnetic field for BL displacement along the domain wall was of the form

$$F_x = 2MH_z\Delta + \frac{\alpha M^2 \dot{H}_z L}{\gamma \chi_y} - \frac{4\pi M^2 \dot{H}_x L}{\gamma \chi_y}, \tag{1}$$

where $\mathbf{M}$ is the saturation magnetization, H_z and H_x respectively the external magnetic-field components normal to $\mathbf{M}$ domains and parallel to these vectors, α the dissipation pa-

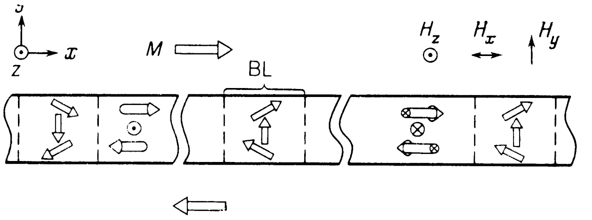

FIG. 1. Distribution of the magnetization (M) in a 180-degree domain wall containing vertical Bloch lines.

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rameter in the Landau-Lifshitz-Gilbert equation,[1] Δ the domain-wall thickness, γ the gyromagnetic ratio, L the distance between the BL in the wall, and $\varkappa_y$ the coefficient of the elastic force that returns the BL to its initial position upon its displacement along the y axis. It is seen from this expression that the BL displacement along the domain wall is due not only to the field (H_z) that magnetizes the wall directly. The force F_x depends on H_x, which displaces the wall, or more accurately on the character of the variation of both H_x and H_z with time.

Our aim was to investigate the influence of a constant magnetic field H_y, perpendicular to the plane of a 180-degree domain wall in an yttrium iron garnet, on the characteristics of the BL motion, under conditions when they oscillate about an equilibrium position and are made to drift by the alternating field H_x. The field H_y, as assumed, should magnetize the Bloch lines (or reversed their magnetization) on account of the displacement of the Bloch points, and consequently alter the characteristics of the BL motion in both weak and strong magnetic fields. In the course of these investigations we paid attention also to the elimination of the possible causes, noted above, of the discrepancy between the experimental and theoretical data.

EXPERIMENT

We investigated the motion of BL along a 180-degree domain wall in a single-crystal yttrium iron garnet placed in a homogeneous sinusoidal field $H_x = H_x^0 \sin 2\pi\nu t$, which was produced by Helmholtz coils of 6 mm radius. The 180-degree walls containing the investigated BL separated domains (Fig. 1) magnetized in the (112) plane of a slab measuring $6\times0.5\times0.04$ mm, the long edge of which coincided with the $[11\bar{1}]$ direction. The oscillations of these walls under the influence of the field H_x produced gyrotropic forces that varied with the field frequency ν and acted on the BL in the wall plane. The amplitude of the force F_x proportional in accordance with (1) to the product $H_x^0\nu$, was maintained constant in the investigation of the BL amplitude-frequency characteristics by setting an appropriate value of H_x^0 when ν was varied. Simultaneously with the alternating field H_x, a constant uniform field H_y was applied to the crystal in a direction normal to the wall.

The BL displacements along the domain wall were monitored by measuring with a photomultiplier (PM) the intensity of the polarized light (with the Nicol prisms slightly uncrossed) passing through a domain-wall local section of dimension ($\sim 10\,\mu$m) somewhat smaller than L. The photomultiplier output voltage, whose change corresponded to the BL displacement (x) in the photometered section,[4,5] was fed to a stroboscopic (S7-8) or storage (S8-11) oscilloscope [to record the motion $x(t)$ of the BL], or to an SK4-59 spectrum analyzer (to determine the spectral composition of the BL oscillations), or else to an SMV11 selective microvoltmeter [to measure the $x_0(\nu)$ dependences].

The characteristics of the nonlinear BL motion under BL drift conditions were investigated with an S8-11 storage oscilloscope or by applying to the crystal a short-duration sinusoidal field H_x (Ref. 6). The magneto-optic signals reflecting the drift of the BL were also investigated with a spectrum analyzer to determine their harmonic contents.

For the investigation of periodic signals we used a "MERA-CM3A" computer. It controlled the magneto-optic setup, carried out the preliminary statistical reduction of the signal after a large number of measurements to increase the signal/noise ratio, calibrated and normalized the signals, eliminated the slow parasitic signal drift, and stored, recorded, reduced, and displayed the data on a remote monitor screen.

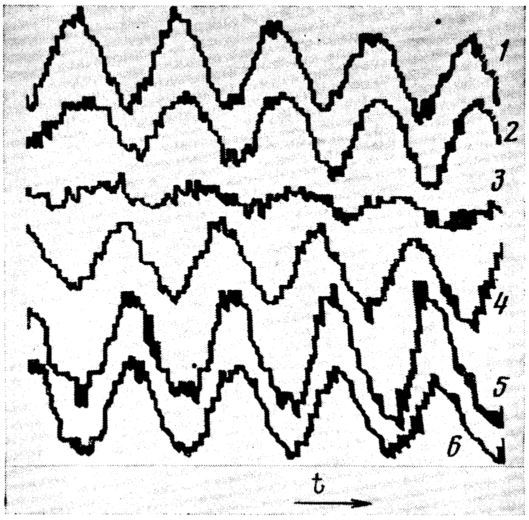

FIG. 2. Time oscillograms (fed from the computer memory to the monitor screen), recorded in response to a field H_x of amplitude $H_x^0 = 3.7$ mOe ($\nu = 0.7$ MHz) and to a field H_y of strength: 1— – 2.1 Oe, 2— – 0.7, 3—0.4, 4—0.7, 5—1.4, 6—2.1.

EXPERIMENTAL RESULTS

1. Figure 2 shows typical oscillograms of the oscillations of one and the same BL acted upon by a sinusoidal field H_x at different values of the constant field H_y. Comparison of the oscillograms shows that the amplitude of the BL displacement in the field H_x depends on the H_y intensity, and reversal of the polarity of the crystal-magnetizing field shifts the phase of the BL oscillations by π. Figure 3 shows the dependences of the amplitude (x_0) of the BL oscillations on the frequency (ν) of the field H_x, measured at a constant value of the product $H_x^0\nu = 609$ Oe·Hz and at various H_y intensities. Here, too, attention is called to the strong influ-

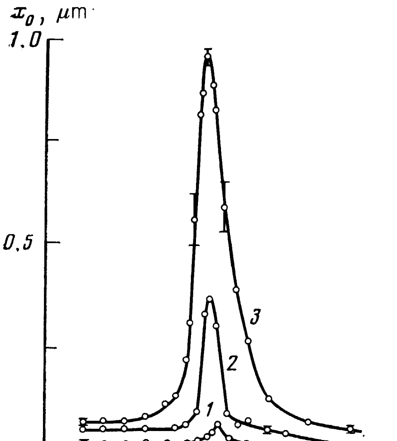

FIG. 3. Amplitudes of BL oscillations (x_0) vs the frequency (ν) of the sinusoidal field H_x measured at $H_x^0\nu = 609$ Hz·Oe and at different values of H_y: 1—9, 2—0.4, 3—2.1 Oe.

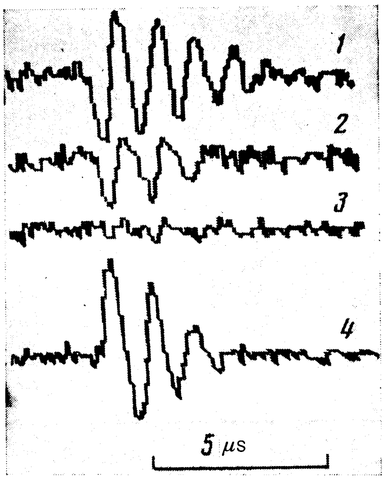

FIG. 4. Free BL oscillations produced after applying to crystal a steplike 11-mOe field H_x, in the presence of a field H_y of strength 1 = 1.4 Oe, 2—0, 3— − 0.7, and 4— − 2.8.

ence of the field H_y on the BL oscillation amplitude. In addition, a dependence of the resonance frequency on H_y was observed.

Investigation of a large number of Bloch lines has shown that their initial states vary. It is manifested in differences of their response to the field H_x and in the character of its dependence on H_y. Figure 4 illustrates, using as an example free damped BL oscillations initiated by applying a steplike field H_x, a situation in which an increase of H_y of one polarity increases the amplitude of the free BL oscillations (curve 1), whereas an increase of H_y of opposite polarity is accompanied initially by a decrease of the oscillation amplitude to zero (curve 3), followed by an increase (curve 4). The newly produced BL oscillations have different directions, in the corresponding half-periods of the oscillations, than those measured at $H_y > -700$ mOe. Note also that the measured $x_0(\nu)$ dependences near the resonant displacement of the BL had frequently a more complicated form than shown in Fig. 3 and had several peaks.

2. The plots of the resonant shift of the BL, shown in Fig. 3, were recorded in a very weak field H_x, such that a Fourier analysis (with the aid of a spectrum analyzer) of the magneto-optic signal revealed a single peak, indicated that under these conditions the BL oscillated only at the frequency of the external field H_x. With increase of the amplitude H_x^0 of the latter, however, additional harmonics appeared.

The change of the form of the spectrum with increase of the field amplitude is illustrated in Fig. 5. The field frequency ($\nu = 170$ kHz) was much lower than the resonance frequency of the BL displacement ($\nu_r = 600$ kHz) in weak fields. It can be seen from Fig. 5 that with increase of H_x^0 there appear and are amplified also additional BL oscillation harmonics that are multiples of the fundamental BL oscillations. It is significant that the fastest growing amplitude is that of the spectrum peak whose frequency is closest to ν_r (Fig. 5, b and c). Under conditions of nonlinear resonance, this frequency decreased substantially with increase of H_x^0 (Ref. 4). This circumstance explains why the third-harmonic amplitude decreased when H_x^0 was increased to 33.6 mOe, while that of the second increased (Fig. 5d). Such "subharmonic resonances" of the BL displacement were sometimes recorded also for $\nu > \nu_r$. The changes of the signal level on

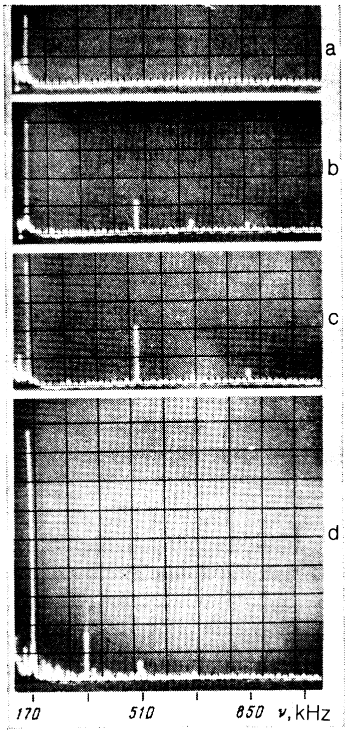

FIG. 5. BL oscillation spectra in field H_x: $\nu = 0.17$ MHz, $H_x^0 = 18$ (a), 20 (b), 22 (c), and 33.6 (d) mOe.

the oscillograms at the lowest frequencies (Fig. 5) are determined by the amplitude-frequency characteristic of the instrument itself.

Nonlinear BL motion was observed on increase of not only the amplitude of field H_x^0 but also of the field H_y (in particular, Fig. 2 shows that an increase of positive-polarity H_y from 1.4 to 2.1 Oe no longer increases x_0 as in the case of weaker fields). The $x_0(\nu)$ curves assumed the form typical of a patently nonlinear resonance. With further increase of H_x^0 or H_y, small-amplitude fluctuations became observable in the BL equilibrium positions, and for the critical value of H_x (H_{cr})[8] the aforementioned irreversible unidirectional motion of the entire BL system in the wall set in.[6]

The plot of $\bar{x}(H_y)$ shown in Fig. 6 reflects a typical example of the influence of the magnetizing field H_y on the velocity of the BL drift initiated by a sinusoidal field H_x. The values of x (from which the BL drift velocity can be estimat-

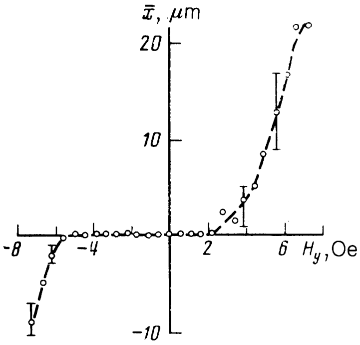

FIG. 6. Average irreversible unidirectional BL displacement (x) corresponding to the action of one train of the field H_x (duration 10 μs, carrier frequency $\nu = 0.4$ MHz, $H_x^0 = 38$ mOe) vs the H_y field intensity. The average subdomain dimension is ~75 μm.

ed) were obtained by averaging repeatedly measured ($\gtrsim 50$ times) values of the irreversible displacement of one and the same BL, due to the short-duration (10 μs) action of the field H_x on the crystal. The BL was returned before each measurement to the initial position by using the same fields with the direction of H_y reversed. The amplitude of H_x was chosen to be somewhat smaller than the critical value H_{cr}, so that in the absence of H_y the BL oscillated only near the initial equilibrium position. The action of the field H_y, as seen from Fig. 6, stimulated the appearance of the BL drift and its enhancement. A characteristic feature is that the critical values of H_y of opposite polarity, which determine the start of the BL drift, are not equal to one another.

When the amplitude of H_x was set higher than H_{cr}, no horizontal segments appeared on the measured $x(H_y)$ plots, and the BL drift direction coincided with that of the BL displacements corresponding to the right-hand branch of Fig. 6. This direction of the BL drift was restored also after turning of the negative-polarity field H_y used to measure the left-side $\bar{x}(H_y)$ plot shown in Fig. 6.

Figure 7a shows a single oscillogram obtained under BL drift condition at $H_y = 0$ and indicating the successive passage of "dark" and "light" subdomains through the photometered section of the domain wall. The maximum and minimum values of the signal were reached when the "light" and "dark" subdomains occupied fully the photometered section. The fact that the oscillogram is not periodic indicates a nonuniform motion of the BL under conditions when the amplitude of H_x is only insignificantly higher than the critical H_{cr}. With a weak field H_y applied to the crystal, the magneto-optic signal, as seen from Fig. 7b, assumed a form closer to periodic, attesting to stabilization of the BL drift velocity and to equalization of the sizes of the moving subdomains. It is seen under these same conditions that a change of the level of such a quasiperiodic signal is accompanied by high-frequency oscillations at a frequency equal to that of the field H_x. The BL moving in the same direction oscillated simultaneously at the frequency of the field H_x and gave rise to high-frequency signal oscillations at the instants of passage through the photometered section. A phase-shift analysis of the oscillations has shown that the neighboring BL oscillated in counterphase.

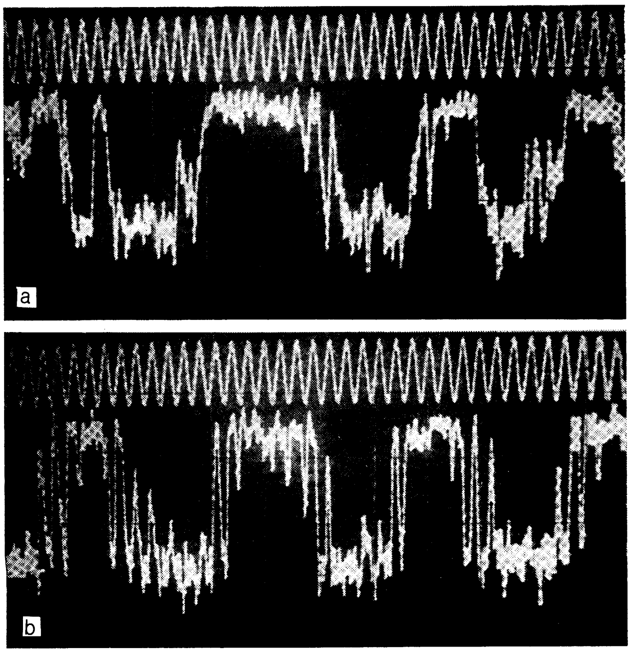

FIG. 7. Single oscillograms measured at $H_x^0 = 0.1$ Oe ($\nu = 350$ kHz) and $H_y = 0$ (a) and 8.4 Oe (b). Upper oscillograms—the field $H_x(t)$.

By using the method[6] of successive photography of the domain wall after short-duration action on the crystal by a field H_x of amplitude capable of producing BL drift, it was possible to demonstrate directly that reversal of the polarity of the constant field H_y reverses the drift direction of the entire BL system in the wall. The displacements of the different BL, however were nevertheless unequal. The $\bar{x}(H_y)$ dependences measured for different BL were likewise different.

Figures 8a–8d show oscillograms illustrating the change induced by the field H_y in the spectrum of the BL-drift signal. The initial spectrum was plotted in the absence of H_y under the same conditions as the oscillogram in Fig. 7a. The principal peak on it coincides with the frequency of the field H_x. This indicates that at $H_y = 0$ the BL moving in the same direction oscillate simultaneously at the H_x frequency. The broadening of the peak at the base indicates that the stimulated BL oscillations are amplitude modulated. Since the magneto-optic signal due to the BL displacement changes only at the instant when the BL pass through the photometered section of the wall (Fig. 7), the recorded high-frequency signal corresponding to these oscillations is modulated at a frequency equal to the frequency of the appearance of the BL in this section. The modulation frequencies range from 0 to ~ 100 kHz (see the width of the peak at the base), owing to the scatter of the subdomain parameters and the nonstationary character of the BL drift. This is apparently also the cause of the low-frequency oscillations in the initial spectrum.

It can be seen from a comparison of spectra a–d of Fig. 8 that the magnetic field H_y can increase the height of the main peak, (b, c), can convert its base into two side lobes (c, d), and can cause the lf oscillations to vanish (c, d). The latter were transformed into a distinctly pronounced peak at 37 kHz (corresponding to Fig. 8d), which is located outside the spectrum indicated in the figure. The growth of the main peak in the spectrum is determined by the increase of the induced BL oscillations. The onset of side lobes of the amplitude-modulated signal means that the BL drift velocity is stabilized by H_y, and the subdomain sizes become equalized. Some broadening of the side lobes attests to a small scatter of these values.

The same oscillograms contained also BL oscillations at the second harmonic ($\nu = 700$ kHz) which was likewise modulated. It is interesting that the signal modulation frequency at this harmonic is double the modulation frequency of the fundamental and coincides with the frequency of the peak connected with the BL (low-frequency) drift. In addition, the heights of the side lobes exceed the height of the second-harmonic peak. This can be explained by taking into account the phase modulation of the second harmonic of the magneto-optic signal, due to the peculiarities of the signal formation as the oscillating BL move through the photometry section.

Oscillograms e–h of Fig. 8 illustrate the variation of the spectrum of the moving-BL signal, due to the increase of the amplitude of the field H_x at constant H_y. These spectra

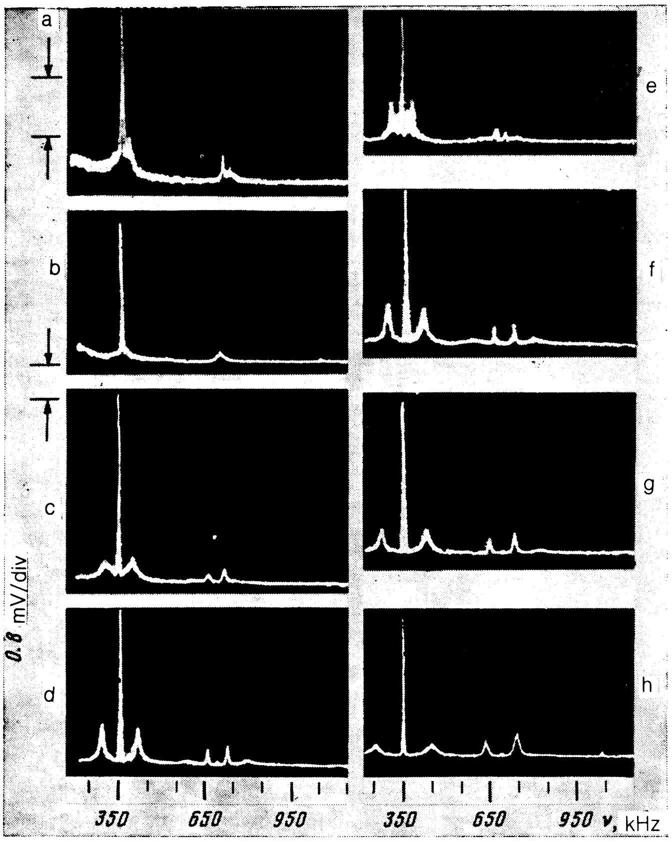

FIG. 8. BL-oscillation spectra measured under BL drift conditions. a—$H_x^0 = 0.1$ Oe, $H_y = 0$; b—$H_x^0 = 0.1$, $H_y = 2.8$; c—$H_x^0 = 0.1$, $H_y = 5.6$; d—$H_x^0 = 0.1$, $H_y = 8.4$; e—$H_x^0 = 0.05$, $H_y = 8.4$; f—$H_x^0 = 0.1$, $H_y = 8.4$; g—$H_x^0 = 0.16$, $H_y = 8.4$; h—$H_x^0 = 0.22$, $H_y = 8.4$. The frequency of H_x is $\nu = 350$ kHz. The larger vertical scale division pertains only to Fig. a, and the smaller one to the remaining ones.

show more clearly the increase of the distance of the side lobes from the main peak, which occurs when H_x^0 is increased and which is determined by the magneto-optic signal modulation-frequency increase apparently caused by the increase of the BL drift velocity. It is also noteworthy that the main peaks on spectra *d* and *h* are lower than on the preceding ones, and continue to decrease with further increase of H_y or H_x^0.

Experiment shows thus that the velocity of the directional motion of the BL depends on the field H_y. If strong enough, this field equalizes the drift characteristics of all the BL and determines the direction of such a nonlinear motion of the BL. In the absence of an external H_y, however, the BL drift direction is governed apparently, as follows from Fig. 6, by the weak internal H_y^i present in the crystal. This field can cause the polarization of spins of one polarity in the BL to predominate over the other polarization that may cause of the BL drift.[7]

DISCUSSION OF RESULTS

The reported experimental data show convincingly that even a relatively weak magnetic field H_y influences strongly the character of the BL motion induced by gyrotropic forces caused by domain-wall oscillations. The sign of the gyrotropic force that causes the displacement of the BL along the wall depends on the direction of the spin rotation in the BL.[3] The obtained experimental data can therefore be explained by assuming that the field H_y caused partial or total polarization or repolarization of the BL. The results could also be due to displacement of existing or created Bloch points. The most convincing evidence in favor of reversal of the direction of spin rotation in BL under the influence of the field H_y is the accompanying change, equal to π, of the phase of the BL oscillations in this field.

Absence of oscillations when the field H_x is applied (Fig. 4, curve 3) occurred apparently when Bloch points (one or several) subdivided the BL into an equal number of sections of opposite polarity, such that the total gyrotropic force acting on the entire BL was zero. Flexural oscillations of the BL should have been excited in this case, but none were observed in the present experiment. In those cases when x_0 decreased on application of the field H_y, the greater part of the BL (or all of them) was most probably polarized in a direction opposite to that of the action of H_y.

If the described processes were actually realized, the observed change of the BL drift direction in the field H_y can be obtained, likewise qualitatively, by taking into account the repolarization of the Bloch lines, which leads to reversal of the sign of an effective force of nonlinear origin[7] that could cause this drift. According to Ref. 7, such a force will act on Bloch lines in a domain wall in one direction, and in the neighboring walls in the opposite directions, if all the BL in the crystal are polarized in one and the same direction. When this direction is reversed, the sign of the force is also reversed, as expected. From this standpoint the experimental fact, that field H_y causes the drift velocities of all the BL in a wall to become equal and to increase, gives grounds for assuming that both the initial BL and those newly generated (in the absence of H_y) frequently contain Bloch points and have different structures. It is unfortunately impossible to obtain from Ref. 7 quantitative estimates of the BL-drift characteristics as functions of the external field and to compare them with the experimental data. What remains unexplained in the theory of Ref. 7 is that the critical field H_x^0 below which no BL drift takes place.[8]

On the other hand, the characteristics of the linear motion of a BL that oscillates about an equilibrium position can be estimated. We calculate the BL effective mass and viscous-friction coefficient on the basis of curve 2 of Fig. 3. As already noted, its measurement revealed no nonlinearity attributes in the character of the BL motion. As applied to the present experimental situation, the theory for a linear oscillator leads to the expressions

$$m_x = a/\omega_r^2, \quad \beta_x=[2a(\varkappa_x-a)]^{1/2}/\omega_r, \tag{2}$$

where

$$a=[\varkappa_x^2-(F_x^0/x_r)^2]^{1/2}, \quad \omega_r = 2\pi\nu_r,$$
$$F_x^0=4\pi M^2 L\omega H_x^0/\gamma\varkappa_y,$$

$x_r = x_0 = 0.37\cdot 10^{-4}$ cm at $\nu = \nu_r = 825$ kHz, and $\varkappa_y = 2.9\cdot 10^3$ g/cm·s^2 was determined experimentally by measuring the dependence of the displacement of the domain wall on the static field H_x; $L = 9.5\cdot 10^{-4}$ cm was measured directly in the field of view of a microscope, $\varkappa_x = F_x^0/x_0(\nu\to 0) = 34.6$ g/cm·s^2 [the value of $x_0(\nu\to 0)$ was determined by extrapolating the $x_0(\nu)$ dependence to the x axis at $\nu = 0$], $\gamma = 1.76\cdot 10^7$ (s·Oe^{-1}), $M = 139$ G, and $\Delta = 10^{-4}$ cm is close to the wall thickness in yttrium iron garnet.[9] Substitution of these parameters in (20) yields $m_x \approx 1.2\cdot 10^{-12}$ g/cm and $\beta_x \approx 0.9\cdot 10^{-6}$ g/cm·s. The value of β_x can furthermore be estimated from the width ($\Delta\nu$) of the $x_0(\nu)$ resonance line at

$$\beta_x=2\pi\Delta\nu\varkappa_x/(2\pi\nu)^2\approx 0.9\cdot 10^{-6}\ \text{g/cm·s}\ . \tag{3}$$

Reduction of curve 3 of Fig. 3 in similar fashion leads to somewhat lower values: $m_x \approx 0.9\cdot 10^{-12}$ g/cm, $\beta_x \approx 0.4\cdot 10^{-6}$ [from Eq. (2)] and $\beta_x \approx 0.7\cdot 10^{-6}$ g/cm·s [from Eq. (3)].

A theoretical analysis[5] of BL motion with allowance for the action of gyrotropic forces on the BL yields the expressions

$$m_x = \frac{1}{\varkappa_y}\left(\frac{2\pi M}{\gamma}\right)^2\left(1+\alpha\frac{2L}{\Lambda\pi^2}\right)$$

$$\text{and } \beta_x = \alpha\frac{2ML}{\gamma\Delta}\left(\frac{\varkappa_x}{\varkappa_y}+\frac{2\Delta^2}{\Lambda L}\right), \tag{4}$$

where $\Lambda = (A/2\pi M^2)^{1/2}$, $\alpha = 15\cdot 10^{-5}$ (Ref. 10). They make it possible to calculate the quantities $m_x = 0.85\cdot 10^{-12}$ g/cm and $\beta_x = 0.2\cdot 10^{-6}$ g/cm·s. From a comparison of these data it can be seen that the experimental values obtained not only for m_x, as in Ref. 5, but also for β_x are of the same order as the calculated ones, and when the field H_y is increased the difference between the experimental and theoretical data decreases. It is therefore quite probable that the BL in yttrium iron garnet contain Bloch points that can be moved by the field H_y. It cannot be ascertained, however, whether total polarization of the BL was obtained under the conditions for which curve 3 of Fig. 3 was plotted, since the $x_0(\nu)$ dependence took a more complicated form with further increase of H_y.

It must be borne in mind that the obtained values of m_x, of β_x, and of the associated natural frequency of the BL oscillations correspond to the case of the most symmetric $x_0(\nu)$ curve fitted to the large experimental material. The overwhelming majority of the measured spectra have complicated shapes, attesting to the existence of various BL oscillation modes in the domain wall. They can be results of flexural oscillations of the BL, of their dependence on the state of the real structure of the magnet, etc.

The field H_y caused small deviations of the magnetization vectors from their initial positions also in neighboring domains, and this changed the final spin rotation obtained by tracing a closed circuit around the BL.[3] The field H_y should therefore alter also the effective mass, meaning also the frequency of the natural oscillations of the BL. The BL mass should apparently decrease in a field H_y, in qualitative agreement with the experimental data obtained for m_x at two different values of H_y.

CONCLUSION

The entire aggregate of the described experimental data justifies the statement that not only the domain walls[9] but also the Bloch lines in yttrium iron garnet can consist of segments of opposite polarity, separated by transition regions, such as the Bloch points whose existence was predicted theoretically for highly anisotropic magnetic films. An external magnetic field normal to the plane of the wall can "magnetize" the BL by displacing the Bloch points, and thereby alter considerably the character of the BL motion under the influence of the gyrotropic force. The BL oscillation-amplitude spectrum has, as a rule, a complicated form that attests to the presence of a large number of natural oscillation frequencies. They can be determined not only by the different states of the BL with respect to the Bloch points and by excitation of flexural oscillations of the BL, but also by the connectivity of the system of Bloch lines and of the domain wall, as well as by the influence exerted on this system by crystal-lattice defects.

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