Spectrum of excitations of a 180° domain wall containing Bloch lines and points

Yu. P. Kabanov, L. M. Dedukh, and V. I. Nikitenko
Institute of Solid State Physics, Russian Academy of Sciences, 142432 Chernogolovka, Moscow Region, Russia

(Submitted 25 March 1994)
Pis'ma Zh. Eksp. Teor. Fiz. **59**, No. 9, 605–609 (10 May 1994)

The spectrum of magnons localized in an isolated 180° domain wall in a YIG single crystal has been studied as a function of the density of Bloch lines and their structure. An induction method and a magnetooptic method were used. A dynamic transformation of the structure of Bloch lines has been observed to result from drift, generation, and annihilation of Bloch points, which cause substantial changes in the characteristics of bending vibrations of the wall.

A magnetooptic method[1,2] made possible the first experimental study of the spectrum of 2D magnons localized in 180° domain walls in a ferromagnet. It was established that Bloch lines essentially suppress such excitations of the wall. In this letter we are reporting the use of a magnetooptic method and an induction method to study how the structure of Bloch lines affects the amplitude of bending vibrations of a wall. It has been found that subjecting a crystal to magnetic fields which polarize Bloch lines or break them up into quasidomains separated by Bloch points makes it possible to fundamentally change the characteristics of the natural bending vibrations of a domain wall. We show that the observed effects can be explained consistently in terms of drift, generation, and annihilation of Bloch points, which cause a dynamic structural transformation of Bloch lines. The results are described below.

The test sample was a single-crystal yttrium iron garnet (YIG) plate cut in the form of a prism with dimensions of $4.3\times0.2\times0.03$ mm. The sample contained a single 180° domain wall, which separated domains that were magnetized along the long edge of the prism, [111], in the plane of the sample, $(11\bar{2})$. In its initial state the domain wall contained Bloch lines which were nearly parallel to the $(11\bar{2})$ surface of the plate. A balanced winding consisting of a few turns of a conductor was formed around the sample for a study of forced vibrations of the wall. The electrical signal induced in this winding was sent to a spectrum analyzer. The magnetic fields were generated by Helmholtz coils 6 mm in radius. The structure of the domain wall in the static and dynamic states was monitored on the basis of the magnetooptic contrast under a polarizing microscope.

Figure 1 shows the induction signal E as a function of the frequency (ν) of the low-amplitude exciting magnetic field H_{111}, which was applied along the direction of the magnetization in the domains. Curve 1 was recorded for a unipolar wall, produced by briefly raising the field H_{111} to an amplitude which caused a drift of Bloch lines,[3] in the presence of a static auxiliary field $H_{11\bar{2}}$, directed perpendicular to the plane of the plate. This auxiliary field magnetized the domain wall. The field H_{111} caused the Bloch

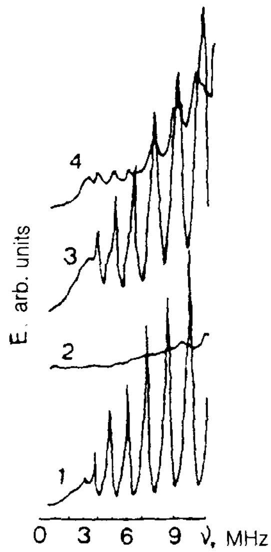

FIG. 1. Amplitude of the induction field, E, versus the frequency (ν) of the exciting field, H_{111} (with an amplitude $H^0 = 1.5$ mOe). *1*—For a unipolar wall; *2–4*—for a wall containing 42 Bloch lines. *3, 4*) Recorded in succession after the application to the crystal, for 0.5 s, of a field H_{111} with a frequency and amplitude of 1 MHz and 18 mOe (curve 3) or 20 Hz and 75 mOe (curve 4).

lines to drift away from the domain wall, while the field $H_{11\bar{2}}$ prevented a nucleation of subdomains with the polarity opposite this field during the drift of these lines. The unipolar state of the wall produced in this manner persisted not only after the field $H_{11\bar{2}}$ was removed, but also during a subsequent slight excitation of the wall by a magnetic field during the recording of $E(\nu)$. The pronounced peaks on curve 1 stem from the excitation of standing bending waves in the domain wall, with a wave vector **k** perpendicular to the magnetization in the domains.[1,2]

After the wall broke up into subdomains, the peaks essentially vanished from the $E(\nu)$ curve (curve 2). After a brief application of a high-amplitude field H_{111} to the sample, however, the bending vibrations of the wall with Bloch lines could intensify again. In particular, after the application of a field H_{111} at a frequency of 1 MHz to the crystal, the bending vibrations of the wall were completely restored (curve 3). Their amplitude could be reduced substantially by subsequently applying the same field, at a lower frequency, to the crystal (curve 4). A study showed that the increase in the amplitude of the bending vibrations of a wall containing Bloch lines occurs when the amplitude of the applied magnetic field exceeds a certain threshold, which depends on the frequency. The effect occurs only at frequencies above 0.4 MHz.

Figure 2 demonstrates how the bending vibrations of a domain wall with Bloch lines (curve 1) are affected by a static magnetic field $H_{1\bar{1}0}$ which is directed perpendicular to the domain wall and which magnetizes the Bloch lines (curve 2). As the field $H_{1\bar{1}0}$ is increased, the amplitude of the bending vibrations may decrease, essentially to zero; when this field is turned off, the amplitude may be partially restored (compare curves 2 and 3). Curve 4 was recorded after the application of a high-amplitude field H_{111} at a frequency $\nu = 1$ MHz to the crystal, as in the case of curve 1,

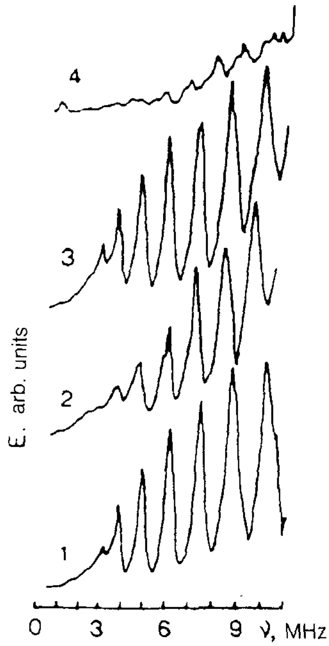

FIG. 2. Curves of $E(\nu)$ recorded (at $H^0=1.5$ mOe) for a 180° domain wall with 40 Bloch lines after the application to the crystal of a field H_{111} ($H^0=18$ mOe, $\nu=1$ MHz) (curve 1), after the subsequent application of a static magnetic field $H_{1\bar{1}0}=12$ Oe (curve 2), and after the latter field was turned off (curve 3). Curve 4 was recorded after the application of a field H_{111} ($H^0=18$ mOe, $\nu=1$ MHz) to the crystal in the presence of a field $H_{1\bar{1}0}=12$ Oe.

but in the presence of a static field $H_{1\bar{1}0}$. This treatment of the crystal substantially reduced the peaks on the $E(\nu)$ curve which stemmed from the bending vibrations of the wall. It gave rise to a small new peak at a frequency $\nu\approx 0.8$ MHz, due to excitation of uniform resonant vibrations of Bloch lines. Their vibration at this frequency was confirmed by direct observation of the lines under a microscope. The resonant vibrations of the lines were detected by an induction method by virtue of their elliptical polarization, which resulted in a quasiresonant vibration of the wall itself.[4]

On the basis of these results it can be asserted that drift, generation, and annihilation of not only Bloch lines, but also Bloch points occurs in a YIG single crystal subjected to a high-amplitude field H_{111}. The generation and drift of these entities occur when the amplitude of the applied field exceeds a certain critical value which depends on ν (as in the cases of the drift of lines and walls[3,5]). As the density of Bloch points in the lines increases, the amplitude of their vibrations along the wall due to gyrotropic forces should decrease.[6] The reason is that parts of the lines which are separated by Bloch points and which are moving along the wall in opposite directions become shorter when they are displaced along with the wall. A decrease in the amplitude of the vibrations of the Bloch lines along a wall should be accompanied by an increase in the vibration amplitude of the wall itself.[7] Accordingly, as more points accumulate on the Bloch lines, the amplitude of the bending vibrations of the wall will increase. A complete restoration of the wall vibration amplitude (curve 3 in Fig. 1) evidently corresponds to a concentration of points at which there is essentially no motion of lines along the wall. At low frequencies of the applied field, an annihilation of Bloch points evidently occurs, resulting in a decrease in their concentration in the lines (curve 4 in Fig. 1).

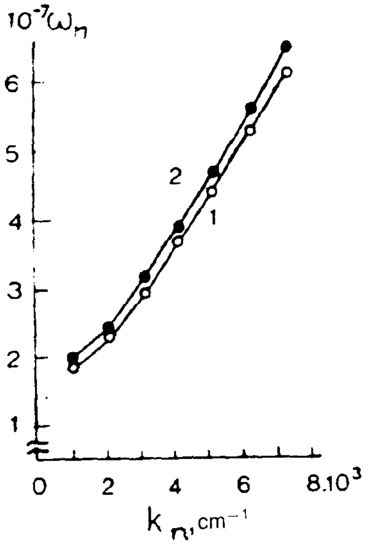

FIG. 3. Dispersion of spin waves localized in a 180° domain wall. *1*—The wall is in a unipolar state; *2*—it contains 42 Bloch lines with Bloch points. The notation is explained in the text proper.

The application of the static field $H_{1\bar{1}0}$ causes a partial magnetization of the Bloch lines,[8] accompanied by a growth of the regions which are polarized in the cores of the lines along $H_{1\bar{1}0}$, an increase in the amplitude of their vibrations along the wall, and thus a decrease in the bending vibrations of the wall (curve 2 in Fig. 2). The field value used in recording this curve, $H_{1\bar{1}0}=12$ Oe, turned out to be insufficient to annihilate neighboring Bloch points characterized by a common topological charge. Evidence that there are repulsive forces between them comes from the partial relaxation of the vibrations of the domain wall which is observed after the field $H_{1\bar{1}0}$ is turned off (curve 3 in Fig. 2).

When a high-amplitude field H_{111} is applied to the crystal along with the static field $H_{1\bar{1}0}$, essentially all the Bloch points drift away from the lines, as in the case of Bloch lines (see the discussion above regarding the method for magnetizing the wall). Accordingly, the bending vibrations of a wall with polarized lines of this sort become negligibly small (curve 4 in Fig. 2). Further evidence for the latter assertion comes from the onset of resonant vibrations of Bloch lines in an oscillating wall (the low-frequency peak on curve 4 in Fig. 2). It was shown in Ref. 9 that a resonant translational vibration of lines in an oscillating wall occurs only after the lines have been magnetized by the field $H_{1\bar{1}0}$.

Intense vibrations of a domain wall with Bloch lines containing Bloch points were observed at an arbitrary density of lines in the wall. It was thus possible to study the behavior of the wall vibrations as a function of the density of Bloch lines. Figure 3 shows dispersion curves plotted from the experimental data. Here $\omega_n=2\pi\nu_n$, where ν_n is the resonant frequency corresponding to a peak on the $E(\nu)$ curve; and $n=0,1,2,\ldots$ is the index of the peak. The wave vector $k_n=\pi n/d$ is perpendicular to the $(11\bar{2})$ surface of the crystal, and $d=30$ μm is the thickness of the sample. Curves 1 and 2 represent the dispersion of quasi-2D spin waves localized in a unipolar wall (1) and in a wall with 42 Bloch lines containing Bloch points (2). The $\omega_n(\mathbf{k}_n)$ curves characterizing the dispersion of quasi-2D magnons in the case of fewer lines in a wall lie between these curves. The slight effect of the Bloch lines with points on the resonant frequencies corresponding to the natural bending vibrations of the wall may be due to the factors mentioned above.

In summary, these results add substantially to our understanding of the nature of nonlinear oscillations of the magnetization in magnetic materials. These results show that drift, generation, and annihilation of topological solitons can occur in systems of a different dimensionality. It is also important to note that these nonlinear processes develop in very weak magnetic fields, at least in the case of a multiaxial magnetic material.

This study was supported by the International Science Foundation.

[1] L. M. Dedukh *et al.*, Zh. Eksp. Teor. Fiz. **94**(9), 312 (1988) [Sov. Phys. JETP **67**, 1912 (1988)].
[2] L. M. Dedukh *et al.*, Acta Phys. Polon. A **76**, 295 (1989).
[3] V. S. Gornakov *et al.*, Zh. Eksp. Teor. Fiz. **86**, 1505 (1984) [Sov. Phys. JETP **59**, 881 (1984)].
[4] V. S. Gornakov *et al.*, Zh. Eksp. Teor. Fiz. **82**, 2007 (1982) [Sov. Phys. JETP **55**, 1154 (1982)].
[5] V. K. Vlasko-Vlasov and L. S. Uspenskaya, Zh. Eksp. Teor. Fiz. **91**, 1483 (1986) [Sov. Phys. JETP **64**, 874 (1986)].
[6] A. V. Nikiforov and É. B. Sonin, JETP Lett. **40**, 1119 (1984).
[7] A. V. Nikiforov and É. B. Sonin, Zh. Eksp. Teor. Fiz. **90**, 1309 (1986) [Sov. Phys. JETP **63**, 766 (1986)].
[8] L. M. Dedukh *et al.*, Zh. Eksp. Teor. Fiz. **97**, 570 (1990) [Sov. Phys. JETP **70**, 317 (1990)].
[9] L. M. Dedukh and Yu. P. Kabanov, Zh. Eksp. Teor. Fiz. **99**, 1632 (1991) [Sov. Phys. JETP **72**, 912 (1991)].

Translated by D. Parsons