Mobility of the Bloch point along the Bloch line

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(Submitted 2 November 1989)
Pis'ma Zh. Eksp. Teor. Fiz. **50**, No. 11, 479–482 (10 December 1989)

The spectrum of oscillations of a Bloch point along a Bloch line in an yttrium garnet ferrite has been measured for the first time. The spectrum was found to be of a relaxational nature. The mobility of the Bloch point, calculated from experimental data, was found to be lower by two or three orders of magnitude than the line and wall mobilities.

The model of a zero-dimensional magnetic-order defect– a Bloch point–which is a special part of a crystal in which the magnetization **M** is reversed in all three directions, was recently introduced in order to describe certain important physical properties of magnets.[1] Malozemoff and Slonczewski[1] and Kufaev and Sonin[2,3] theoretically derived expressions for the mobility and effective mass of a Bloch point in connection with strongly anisotropic, uniaxial materials with $K \gg 2\pi M^2$ (where K is the anisotropy constant). Kabanov[4] was first to directly observe the Bloch points in single crystals of yttrium garnet ferrite (YGF) with $K \ll 2\pi M^2$. In these single crystals one can visually study the Bloch lines and to see how their structure changes from their reaction to a gyrotropic force.[5] The dynamics of the Bloch points, however, is yet to be studied experimentally. In the present letter we present the results of an experimental study of the dynamics of Bloch points under forces oscillations of a Bloch point.

We have used a technique based on detecting forced oscillations of a Bloch line produced as a result of application of a gyrotropic force whose polarization was reversed by an external field.[5] The test samples were thin (~ 30 μm), rectangular yt-

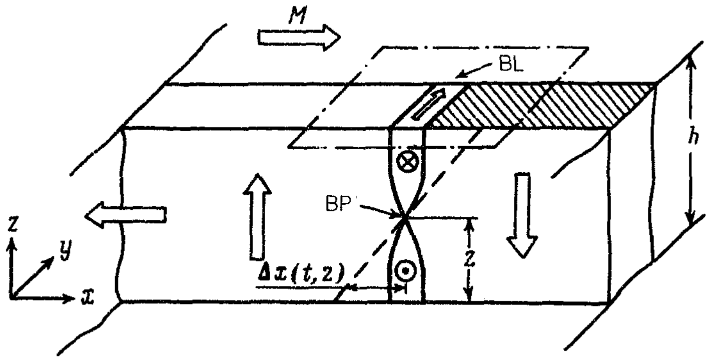

FIG. 1. Schematic diagram of the distribution of magnetization in the test sample which contains a Bloch line (BL) with a Bloch point (BP).

trium garnet ferrite wafers. These wafers contained {110} domains of a 180° neighborhood which were magnetized in the plane of the sample. The domains were separated by domain walls at which the Bloch lines were identified by means of a magneto-optical Faraday effect. This procedure is shown schematically in Fig. 1. The dot-dashed line represents the part of the crystal with a single line, which is scanned photometrically. The change in the intensity I of the magneto-optical signal due to the line's motion was measured by a computer-controlled device which was described in Ref. 5. The sample was inserted into a system of Helmholz coils which produced magnetic fields: an alternating magnetic field $H_y(t) = H_{y0}\cos 2\pi\nu_y t$ and static magnetic field H_y were directed normal to the domain wall, while an alternating field $H_x(\mathrm{t}) = H_{x0}\cos 2\pi\nu_x t$ was oriented along **M** in the domains (Fig. 1).

Upon application of a field $H_x(t)$ to a sample, we detected, as in Ref. 5, a magneto-optical signal which varied with a frequency ν_x. Application of an auxiliary field $H_y(t)$ caused it to be amplitude modulated, with a frequency ν_y. An oscilloscope trace of the signal, $I(t)$, is shown in Fig. 2a. After detecting these signals we found, with the help of a CK4-59 spectrum analyzer, their envelopes ΔI, shown in Figs. 2b–2e. The shape of these envelopes depended on the magnitude of the static field H_y. At $H_y = 3.2$ Oe (Fig. 2b) the signal was nearly harmonic. A lowering of the field H_y led to a change in the shape of the signal due to its inversion in a certain phase of the field $H_y(t)$ (Fig. 2c) and then to a rectification of the sine wave (2d). As the field H_y was lowered further, the signal again became harmonic (Fig. 2e), but now with a phase which differed from the initial phase by π.

The variation in the shape of the envelope of the magneto-optical signal which we described above is governed by the effect of the fields, which are directed along the magnetization in the core of the line, on the distribution in it of the magnetization due to the motion of a Bloch point. The line segments situated on opposite sides of the point are affected by the oppositely directed gyrotropic forces which cause them to shift a distance $\Delta x(t,z)$. The line in this case rotates around the Bloch point, whose z coordinate is specified by the field H_y. The position of the Bloch line core at the time t

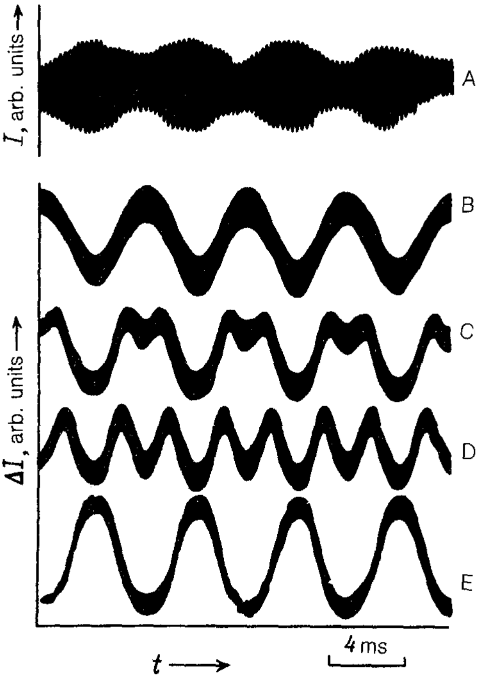

FIG. 2. Oscilloscope traces of a magneto-optic signal before detection (a–$H_{y0} = 0.7$ Oe, $H_{x0} = 16$ mOe) and after detection (b–e–$H_{x0} = 1.2$ mOe, $H_{y0} = 3.9$ mOe) which show the oscillation of the Bloch point at $\nu_x = 400$ kHz and $\nu_y = 0.24$ kHz. The values of the static field H_y are: b–3.2; c–3.05; d–2.7; and e–2.2 Oe.

is shown schematically by the dashed line in Fig. 1. The change in the intensity (ΔI) of the detected magneto-optical signal is proportional to $\int_0^h \Delta x(t,z)dz$, where h is the thickness of the sample. A simple analysis shows that an application of an alternating field $H_y(t)$, which displaces the point, in this case will amplitude modulate the signal. In a static field H_y, which shifts the point to the center of the sample $(z = h/2)$, the alternating field $H_y(t)$, regardless of its polarity, causes ΔI to increase and a signal, shown in Fig. 2d, to appear. If the point oscillates between the surface of the sample and its center, the envelope will have a harmonic shape, and its amplitude, ΔI_0, will be proportional to the oscillation amplitude of the point, Δz_0. This circumstance made it possible to measure for the first time the amplitude-frequency curve of the oscillation of the point.

A plot of the curve of $\Delta I_0(\nu_y)$ is shown in Fig. 3. The frequency ν_x of the field $H_x(t)$ was clearly lower than the resonance frequency of the line (~ 650 kHz), allowing us to virtually eliminate its effect on the $\Delta I_0(\nu_y)$ curve. The inset in Fig. 3 is an example of a Fourier expansion of a detected signal. We see that this signal has no frequencies, except the one which carries ν_y and the combination frequencies $\nu_x \pm \nu_y$. To describe the motion of a point, we can use in this case a linear equation $m\ddot{z} + \beta\dot{z} + \alpha z = 2M\delta\lambda H_{y0}\cos 2\pi\nu_y t$, where m, β, and α are the effective mass and viscous friction and stiffness coefficients, respectively; and δ and λ are the widths of the wall and the line. The coefficient α, which is attributable to the demagnetizing field associated with the magnetic poles at the point on the surface of the wall where the line is situated, is $2M\delta\lambda(\Delta H_y/\Delta z)$, where Δz is the distance the point moves when the

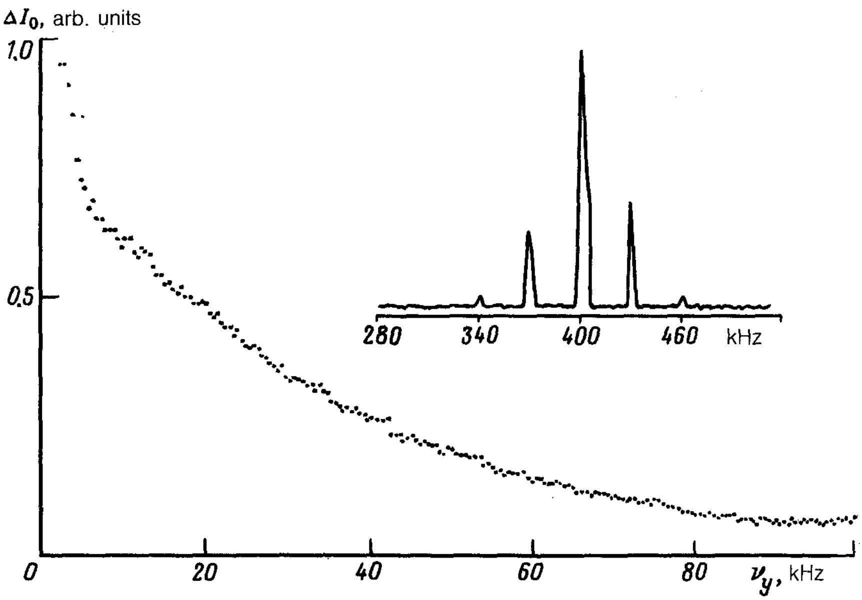

FIG. 3. Oscillation amplitude of the Bloch point versus the frequency of the field $H_y(t)$ at $H_{y0} = 3.9$ mOe. Inset–Oscillation spectrum of the Bloch line at $H_{x0} = 1.2$ mOe, $\nu_x = 400$ kHz and $H_{y0} = 3.9$ mOe, $\nu_y = 30$ kHz.

field H_y is changed by the amount ΔH_y. The viscosity coefficient, which is related to the mobility μ of the point by the relation $\beta = 2M\delta\lambda/\mu$, can be calculated, ignoring the inertia, from the relaxation frequency $\nu_{rel} = \alpha/2\pi\beta$, measured at the level 0.707 $(\Delta I_0)_{max}$ on the $\Delta I_0(\nu_y)$ curve (Fig. 3). The mobility can thus be represented as $\mu = 2\pi\nu_{rel}\Delta z/\Delta H_y$. The values of Δz and ΔH_y were determined in a supplementary experiment, in which we measured the change in the field ΔH_y which caused the point to move a distance $\Delta z = h/2$ from the center of the wafer to its surface. In this case the shape of the modulation signal changed dramatically. It had the shape of a straightened sine wave (Fig. 2d) when the point was at the center of the wafer. The modulation vanished when the point reached the surface. After substituting the values which we obtained $\Delta z = h/2 = 16\mu$m and $\Delta H_y = 1.3$ Oe, and also $\nu_{rel} = 9.9$ kHz, which was found from the analysis of experimental data on a computer by the method of least squares, we estimated the mobility of the Bloch point to be $\mu = 76.4$ cm·s^{-1}·Oe^{-1}. Measurements of the mobility of the point for various lines and walls gave values of the same order of magnitude.

The value of μ which we obtained was lower by two or three orders of magnitude than the values for the wall and line mobilities of the same materials.[6] The current theory[1] of strongly anisotropic, uniaxial magnetic films does not predict a large discrepancy, which may take the form of energy transfer from a Bloch point to different branches of elementary excitations.

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Translated by S. J. Amoretty