Bloch points in an oscillating Bloch line

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A magnetooptic method makes it possible to visualize Bloch points in a Bloch line which is executing a forced oscillation due to gyrotropic forces in yttrium iron-garnet crystals. A generation of Bloch points has been observed. An effect of these points on the characteristics of the oscillations of Bloch lines has also been observed.

Research on the properties of various elements of the domain structure of ferromagnets—domain walls, Bloch lines, and Bloch points—has recently been attracting increasing interest. To a large extent this interest stems from progress in our understanding of nonlinear phenomena in a system of ordered spins, in which these elements serve as topologically stable magnetic solitons. Without a detailed analysis of the specific features of their properties and of the generation processes, it is not possible to solve the fundamental problem of constructing a general theory for the processes by which crystals are magnetized and by which elementary and nonlinear excitations are formed in them.

Methods for observing and experimentally studying the dynamic properties of domain walls and Bloch lines were developed a fairly long time ago.[1,2] The problem of visualizing Bloch points and of developing methods for studying their dynamic properties, one the other hand, has yet to be solved. In the present letter we describe the possibilities of a magnetooptic method for visualizing Bloch points in a crystal of yttrium iron garnet and for studying their properties. We report an experimental study of the production of Bloch points and of their effect on the dynamics of Bloch lines.

The experiments were carried out on a single-crystal wafer with dimensions of $0.8\times0.35\times0.025$ mm. The wafer was broken up by 180° walls into several domains which were magnetized along $\langle 111\rangle$ directions, parallel to the long edge and the (112) surface of the sample (Fig. 1). In the original state, the domain walls were broken up by Bloch lines into subdomains. The spins in the central layer of the subdomains in a wall were oriented perpendicular to the surface. The magnetostatic field associated with these spins unrolled the spins near the surface in a Bloch line along the domain wall, displacing the ends of the line in opposite directions and deflecting it away from the normal to the surface (Fig. 1a). Under a polarizing transmission microscope, in crossed Nicol prisms, this line was imaged in projection onto the plane of the wafer as a dark band between bright subdomains in a wall, which were visualized by virtue of the Faraday effect (Fig. 2a). To obtain information on the characteristics of the uniform or bending vibrations of a Bloch line, we carried out a densitometer study of local regions of a black-and-white image of the wall with a line with uncrossed Nicol prisms, by the method described in Refs. 2 and 3.

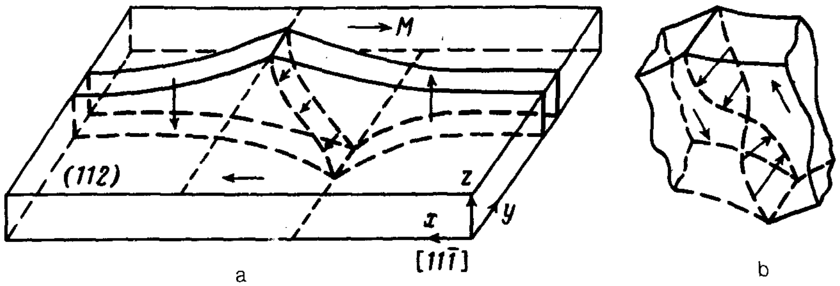

FIG. 1. Shape of a domain wall with a Bloch line; magnetization (M) distributions (a) in a unipolar line and (b) in a line containing a Bloch point.

We know that as a domain wall moves, a gyrotropic force acts on a Bloch line,[1] displacing it along the wall in a direction which depends on the sign of the topological charge of the line, which is in turn determined by the nature of the distribution of spins in it. If the line is completely polarized (in its original state or by a static field H_y, directed perpendicular to the domain wall, which magnetizes the line), the line will

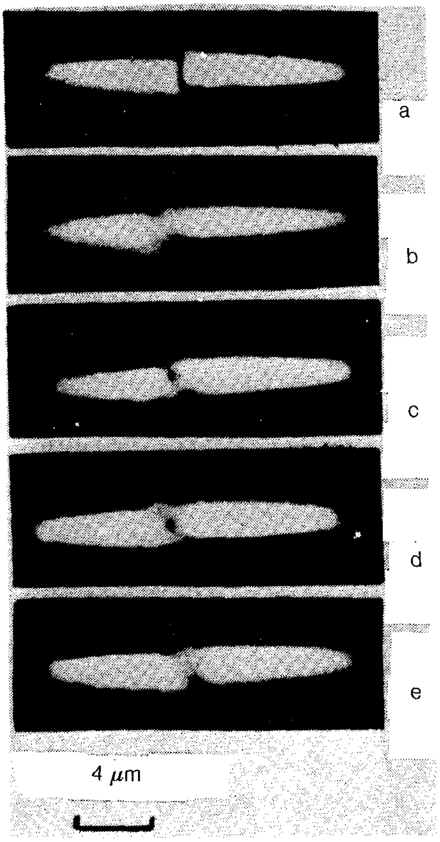

FIG. 2. Photographs of a section of a wall with a single Bloch line recorded in laser light ($\lambda = 63$ nm). a: In the absence of an external field. b–e: In a sinusoidal field H_x at $H_x^0 = 90$ mOe and $\nu = 0.5$ MHz. b—$H_y = +2$; c—$+0.135$; d—0.45; e—-1.5 Oe. The line which is the image of the wall is determined by the diameter of the laser beam in the focal plane.

execute uniform vibrations along the wall in a sinusoidal field H_x directed parallel to the magnetization in the domains. The result will be a blurring of the image of the entire Bloch line (Fig. 2b). Upon a polarization reversal of the Bloch line as the static external field H_y, which is magnetizing it, is reduced, an immobile point arises on the image of the vibrating line near one of the surfaces of the wafer (Fig. 2c). With a further decrease, a change in polarity, and a subsequent increase in H_y, this point moves along the line towards its opposite end (Fig. 2, d and e). A phase analysis has shown that the regions of a Bloch line adjacent to the immobile point execute out-of-phase oscillations. This result means that the point breaks the oscillating line up into two parts, which are acted upon by gyrotropic forces of opposite signs. After the point has traversed the entire line, the phase of its uniform vibrations of course changes by π.

These facts are evidence that the "node" which appears on an oscillating Bloch line is associated with a polarization reversal of this line and is a Bloch point,[1] which separates quasidomains in the line which differ in that the signs of the polarization of these charges are opposite (Fig. 1b). It thus becomes possible to detect and visualize the position of a Bloch point and also to study its motion in yttrium iron garnet single crystals. In a field H_y of low frequency (on the order of 1 Hz), it in fact becomes possible to see the path traced out by a Bloch point in the course of its forced vibrations along the moving Bloch line. The amplitude of these vibrations decreases as the frequency is increased to ~ 1 kHz.

A Bloch point substantially changes the vibration spectrum of a Bloch line. Figure 3 shows the intensity of the magnetooptic signal (which is proportional to the displacement of the Bloch line along the domain wall) versus the frequency of the field H_x according to a densitometer study of half of a Bloch line. Curve 1 was recorded under conditions such that the line was magnetized by a field H_y. This curve has a single and clearly defined peak, which reflects a resonance of a uniform displacement of a Bloch line. Curve 2 in Fig. 3 was recorded during the vibration of a line at whose

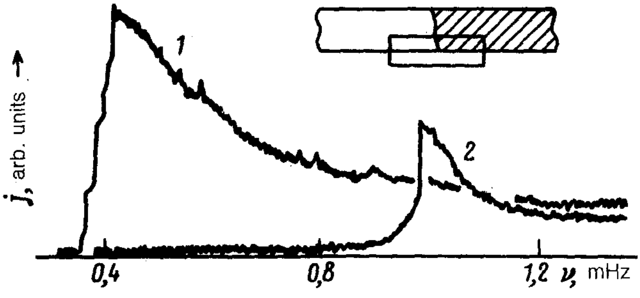

FIG. 3. Frequency dependence of the magnetooptic signal J in a field H_x measured through a photometric study of the lower half of an image of a section of a wall with a Bloch line. $H_x^0 = 15$ mOe. 1—$H_y = 3$ Oe (the line is magnetized); 2—$H_y = 0.27$ Oe (a Bloch point has been introduced at the center of the line). The inset is a diagram of the image of a Bloch line in the case of uncrossed Nicol prisms of the microscope. The region subjected to the photometric study is the region bounded by the rectangle.

center a Bloch point was introduced beforehand by means of H_y. In this case the peak on the $J(\nu)$ curve, which is responsible for the uniform resonance of the Bloch line, is missing, but we see a new peak (at $\nu \approx 1$ MHz), which is determined by a standing wave for which the length of the vibrating line is a half-wave, and the node is at the center of the line, i.e., where we put the Bloch point (Fig. 2d).

Studies of the spectra of the forced vibrations of Bloch lines, along with a direct observation of the oscillating lines, have shown that Bloch points are created in a Bloch line even in the absence of a static field H_y, which reverses the magnetization of the line, if the amplitude of the exciting field, H_x, exceeds a certain level. In particular, as the frequency of the field H_x is varied, we observed the creation (or disappearance) of Bloch points near the surface of the wafer at certain values of this frequency, and we observe a motion of these points along the Bloch line. At resonant frequencies corresponding to the excitation of standing bending waves on the Bloch line, the Bloch points coincide with nodes of these waves. This result may reflect the specific features of the bending vibrations of a vortex-like magnetic soliton which a Bloch line constitutes. Another possibility is that, as the bending vibrations of the line are formed, Bloch points nucleating at the surface of the sample move into regions of a line which are vibrating with the smallest amplitude.

[1] A. P. Malozemoff and J. C. Slonczweski, Magnetic Domain Walls in Bubble Materials, Academic, Orlando, 1979.

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