Anomalous coercive force of Bloch point in iron single crystals

V. E. Zubov, G. S. Krinchik, and S. N. Kuz'menko
M. V. Lomonosov Moscow State University

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The coercive field of a Bloch point near the surface of iron whiskers has been measured for the first time. This field is more than an order of magnitude greater than the coercive field of vertical Bloch lines and more than three orders of magnitude greater than the coercive field of a domain wall in the same crystal.

Magnetic crystals are known to contain microstructural elements of various dimensionalities: domain walls, Bloch lines, and Bloch points. Domain walls and vertical Bloch lines have been studied in detail,[1] while the experimental work on point structures is still in its infancy. For example, the observation of Bloch-point features in the surface region of 180° domain walls of iron single crystals has been reported.[2] The static structure where domain walls reach surfaces and the characteristics of Bloch points were studied in more detail in Ref. 3. The existence of a Bloch point stems from the asymmetric structure of a 180° domain wall in the surface region, as has been observed experimentally.[4] It is a consequence of the appearance of a Néel component of the magnetization (a component perpendicular to the plane of the domain wall). The observed structure agrees best with the model of an asymmetric Bloch wall which was proposed by Hubert[5] and which is shown in the inset in Fig. 1. The energy of the wall does not depend on the direction in which it is distorted in the surface region; i.e., this energy is degenerate with respect to the sign of the Néel component of the magnetization. The Bloch point is a micromagnetic element which separates subdomains differing in polarity (Fig. 1) in a one-dimensional surface structure of the Bloch-line type, while the polarity of the domain wall in the interior remains unchanged.

In this letter we are reporting a study of the displacement of a Bloch point by an external magnetic field. As in Refs. 2 and 3, the measurements were carried out on iron whiskers produced through reduction of iron halides by hydrogen. In the experiments we used samples of square cross section with a side $d = 50$–$140\ \mu$m and a length $L = 2$–10 mm, with optical-quality (100) faces. The samples contained only a single 180° domain wall, at the center, running along the axis of the crystals, parallel to the lateral faces. The displacement of the Bloch point was studied in a field directed parallel to the Néel component of the magnetization (H_x) and also in a field directed parallel to the magnetization at the center of the domain wall (H_z; Fig. 1). The magnetic fields were produced by Helmholtz coils. The measurements were carried out with the magnetooptic micromagnetometer described in Ref. 6. As the slit of the photodetector was moved in the direction parallel to the main wall (along the y axis), the magnetooptic effect was observed on only the part of the crystal surface which had undergone magnetization reversal as a result of oscillations of the Bloch point along the domain wall driven by the alternating magnetic field. The frequency of the magne-

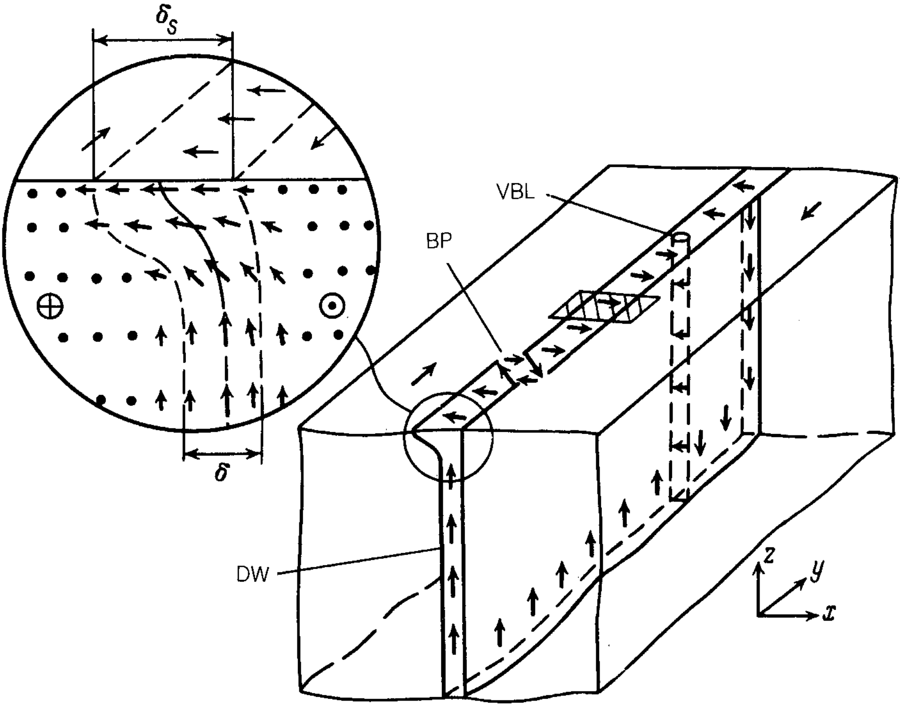

FIG. 1. Region of a 180° domain wall containing a vertical Bloch line and a Bloch point. The inset shows the model of an asymmetric 180° domain wall proposed by Hubert.[5] δ—Effective width of the domain wall in the volume; δ_s—the same, at the surface.

tization reversal was 60 Hz. The magnetization was studied on local regions, 0.3×2 μm^2 in size, on the surface of the sample, with the long dimension of the rectangle running perpendicular to the domain wall (the hatched region in Fig. 1). We measured the equatorial Kerr effect δ^e, caused by the Néel component of the magnetization. The half-width of the $\delta^e(y)$ curves determines the amplitude (Δ) of the displacement of the Bloch point from its equilibrium position. Figure 2 shows curves of $\delta^e(y)$ for various fields H_x. We can determine the field dependence of Δ from these curves. Figure 3 shows the results of measurements of $\Delta(H_x)$ for several Bloch points. The experimental points are seen to conform well to straight lines whose slope determines the susceptibility of the surface region of the domain wall due to the displacement of the Bloch point. This susceptibility can be characterized by the coefficient $K_x^{\rm BP} = \Delta/H_x$. For the Bloch points which were studied, this coefficient lies in the range 0.3–0.5 μm/Oe. An extrapolation of the straight lines describing the dependence $\Delta(H_x)$ to the value $\Delta = 0$ gives us the coercive field of the Bloch point ($H_c^{\rm BP}$), as in the case of a domain wall.[1] The field $H_c^{\rm BP}$ determined in this manner lies in the range 30–50 Oe for all the Bloch points studied. The measurements revealed that the Bloch point did not shift in a field H_z.

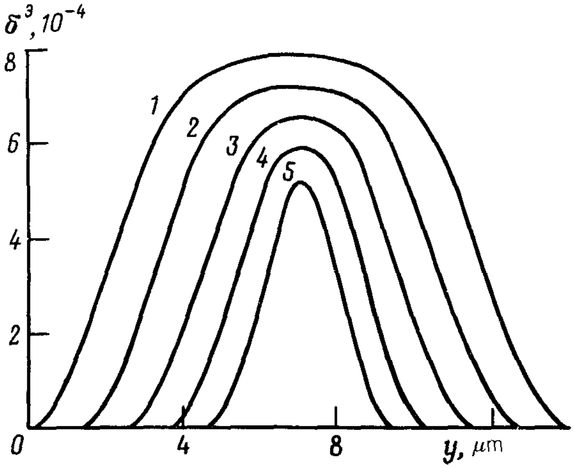

FIG. 2. Equatorial Kerr effect due to vibrations of a Bloch point for various field amplitudes H_x. 1—$H_x = 64$; 2—60; 3—54; 4—50; 5—48 Oe.

For comparison, we carried out corresponding measurements of the displacement of vertical Bloch lines and domain walls in a magnetic field in the same samples. The coefficient K_z^{VBL}, which characterizes the magnetic susceptibility of the domain wall during the displacement of a vertical Bloch line in a field H_z, increases with increasing thickness of the sample and lies in the interval 0.1–1 μm/Oe. The coercive field for the displacement of a vertical Bloch line is 1–3 Oe. A vertical Bloch line is not shifted in a field H_x. Measurements of the coercive field of a domain wall (H_c^{DW}) revealed that H_c^{DW} is lower than 0.01 Oe. As we go from a domain wall to a vertical Bloch line, the coercive field thus increases by two or three orders of magnitude, and as we go from a vertical Bloch line to a Bloch point, it increases by more than another order of magnitude.

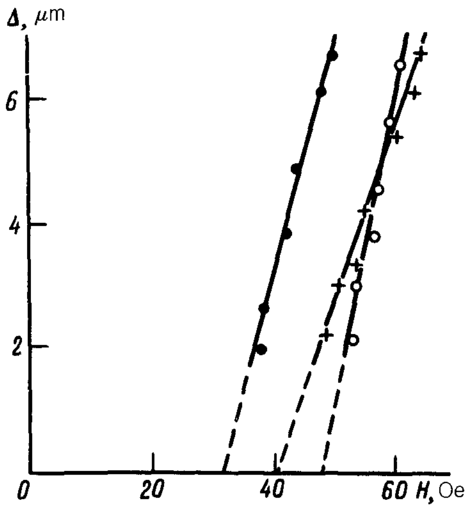

FIG. 3. Vibration amplitude of the Bloch point versus the field amplitude H_x.

These results, along with observations of a similar effect for domain walls and vertical Bloch lines in other materials,[1,7] suggest that the sharp differences in H_c are due primarily to the dimensionality of the microstructural elements. The validity of this hypothesis can be illustrated for the case in which the size of the defects responsible for the coercivity is smaller than the typical size of the microstructures under study (δ). The field H_c is found from the condition that the pressure exerted on the microscopic object by the external field is equal to the retarding force (F_c) exerted by the crystal defects. In other words, this field is found from the equation $2SI_sH = F_c$, where I_s is the saturation magnetization, and S is the effective area of the element. The force F_c is determined by fluctuations in the number (N) of defects in the volume of the microscopic object (V) (Ref. 8); i.e., we have $F_c \sim \Delta N \sim \sqrt{N} = \sqrt{nV}$, where ΔN is the fluctuation in N, and n is the volume density of defects. We thus find that the coercive field is proportional to $\sqrt{V/S}$. For domain walls, vertical Bloch lines and Bloch points we have, respectively, $S_{\rm DW} = dL$, $S_{\rm VBL} \simeq \delta d$, $S_{\rm BP} \simeq \delta^2$, $V_{\rm DW} = \delta dL$, $V_{\rm VBL} \simeq \delta^2 d$, and $V_{\rm BP} \simeq \delta^3$. With $L = 10$ mm, $d = 100\,\mu$m, and $\delta \simeq 0.2\,\mu$m, we find the ratios of the H_c values for the various microstructural elements: $H_c^{\rm DW}: H_c^{\rm VBL}: H_c^{\rm BP} \sim 1:200:5000$. These results agree with the experimental results.

We note in conclusion that the coercive field of a Bloch point is a very sensitive measure of the quality of the material.

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