Experimental observation of "Bloch-point" features in a domain wall

V. E. Zubov, G. S. Krinchik, and A. D. Kudakov
M. V. Lomonosov Moscow State University

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A magnetooptic method has been used to study the fine structure of a Bloch wall at the surface of iron single crystals. This fine structure is unambiguously related to the direction of the asymmetric curvature of the wall near the surface. Structural features of the Bloch-point type have been seen for the first time in an asymmetric Bloch wall.

Vertical Bloch lines have recently become the subject of an active experimental research program because of their possible use in memories.[1] On the theoretical front, there have been detailed studies[2] of the structure of Bloch lines—lines separating subdomains of different polarities in a domain wall—and Bloch points—points separating subdomains of Bloch lines. On the experimental front, in contrast, Bloch points have yet to be observed.

In this letter we report the observation, by a magnetooptic method, of structural features of the Bloch-point type in an asymmetric 180° Bloch domain wall at the surface of iron single crystals. A previous magnetooptic study[3] of 180° domain walls in iron revealed that as it approaches a surface, a wall becomes several times broader and acquires an asymmetric shape, because of the appearance of a Néel component of the magnetization (i.e., a component perpendicular to the plane of the domain wall). In the present experiments we used a refined magnetooptic apparatus with a resolution in the micron range to pursue the study of the structure of domain walls in iron whiskers (filamentary single crystals). The whiskers had optically perfect (001) faces; they ranged in length from 5–10 mm, and their transverse dimensions were $\sim 50\times 50\ \mu m^2$. Some 180° domain walls, parallel to two (100) faces, lay at the center of the whisker along its [010] long axis. The domain walls were studied by measuring the equatorial Kerr effect (a magnetooptic effect), caused by the existence of the Néel component of the magnetization, during oscillations of the domain wall driven by an alternating magnetic field applied parallel to the [010] axis. The magnetization distribution was studied in local areas with dimensions of $0.3\times 1\ \mu m^2$ on the surface of the sample.

Figure 1 shows the x profile of the equatorial Kerr effect (line 1) from an experiment in which the domain wall was driven at an amplitude of $0.1\ \mu m$ (the x and y axes lie in the plane of the face of the whisker, respectively perpendicular and parallel to the plane of the domain wall; the z axis runs perpendicular to the plane of the face). Since the equatorial Kerr effect is proportional to the derivative $\partial I_x/\partial x$, we can use the curve of the equatorial Kerr effect to reconstruct the profile $I_x(x)$ (I_x is the projection of the magnetization vector **I** onto the x axis). This profile is shown by line 2. The shape of the curve of the equatorial Kerr effect from the domain wall did not change

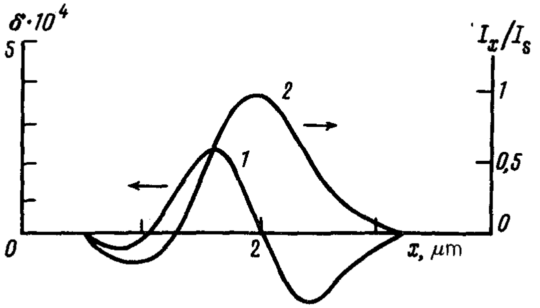

FIG. 1. 1—Profile of the equatorial Kerr effect [$\delta(x)$] caused by the existence of a component I_x in a domain wall, for the case of small oscillations of the domain wall; 2— distribution of the Néel component of the magnetization, $I_x(x)$.

when we raised the frequency of the alternating magnetic field from 20 Hz to 100 kHz. As we will see below, the asymmetry of the profile $I_x(x)$ in a domain wall results from an asymmetric curvature of **I** at the surface; the existence of this curvature leads to a significant decrease in the fringing fields. The observed distribution of the magnetization in the 180° domain wall near the surface corresponds best to the model of an asymmetric Bloch wall which was proposed by Hubert.[4]

Figure 2 shows curves of $I_x(x)$ recorded near a point at which a vertical Bloch line emerges at the surface. In the first case, the direction of the curvature of the domain wall is the same on the two sides of the vertical Bloch line; in the second case, the directions are different. Since the signs of I_z in the domain wall on the different sides of a vertical Bloch line are different in the interior of the crystal, the signs of I_x at the surface should be different on the right and left of the vertical Bloch line in the first case; in the second, they should be the same (the sign of I_x is determined by the order in which the absolute negative and positive extrema appear on the curve of the equatorial Kerr effect, as can be seen clearly in Fig. 1). We also see from this figure that when we move along the domain wall and through the vertical Bloch line, in the first case there is no lateral displacement of the curves of the equatorial Kerr effect, while in the second case there is such a displacement, ~ 0.4 μm. In other words, this displacement is comparable to the width of the domain wall. It is natural to suggest that there is no displacement of the wall near the vertical Bloch line in the interior, so the

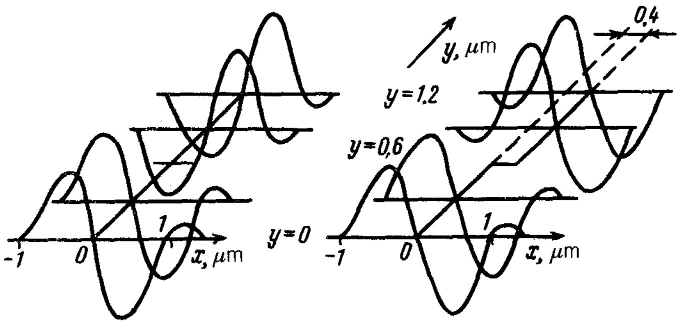

FIG. 2. Families of curves of the equatorial Kerr effect corresponding to curve 1 in Fig. 1, for two cases in which a vertical Bloch line emerges at the surface of the crystal.

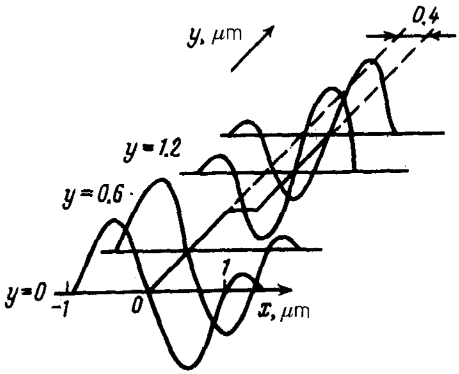

FIG. 3. Family of curves of the equatorial Kerr effect corresponding to curve 1 in Fig. 1, near a Bloch point at the surface of the crystal.

observed displacement in Fig. 2b is further evidence of an asymmetric curvature of the domain wall at the surface. The smallest of the three extrema on the curve of the equatorial Kerr effect always lies on the side opposite the direction of the curvature of the domain wall.

Figure 3 shows yet another structural feature observed experimentally in a domain wall at the surface. As we move along the y axis, there is a lateral displacement $\sim 0.4\ \mu$m, and there is a change in the order at which the maxima of the equatorial Kerr effect appear. In other words, there is a change in the sign of the magnetization in the domain wall. This feature is not related to the emergence of the vertical Bloch line at the surface (both possibilities for the emergence of a vertical Bloch line at the surface were discussed above); it is instead a singular point which separates subdomains of different polarity in a one-dimensional near-surface structure of the Bloch line type, while the polarity of the domain wall in the interior remains unchanged. Consequently, singularities of this type in the structure of a domain wall near the surface can quite naturally be called "Bloch points." Observations show that Bloch points in asymmetric Bloch domain walls are far more common than cases in which a vertical Bloch line emerges at a surface.

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