Faraday effect in a magnetized domain wall

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A Bloch domain wall has been transformed into a Néel domain wall (BDW→NDW) for the first time. The critical field for the BDW→NDW transition and the width of the Néel domain wall have been determined. The magnetization-reversal curve has also been measured for a Bloch domain wall in a longitudinal field (this is the transition from a right-handed domain wall into a left-handed domain wall). This curve is determined by displacements of Bloch lines in a domain wall.

Two basic types of domain walls have been recognized in ferromagnets: a Bloch domain wall (BDW), in which the rotation of the magnetization vector M_s from one domain to another occurs in the plane of the wall, and a Néel domain wall (NDW), in which M_s rotates in the plane perpendicular to the domain wall. A transverse external magnetic field applied in the direction perpendicular to the plane of the domain wall can cause a BDW→NDW transition, while a longitudinal external field can cause a transition from a right-handed domain wall to a left-handed domain wall (RHW→LHW). The BDW→NDW transition has not been seen experimentally.

The present study was carried out to directly observe the magnetization of a BDW in longitudinal and transverse magnetic fields. Our new method for detecting a structural change of the domain wall is based on the circumstance that the Faraday effect measured for an isolated domain wall can be used to detect the change in the magnetization of a domain wall during the application of an external magnetic field to it.

The measurements were carried out in transmitted light on the magnetooptic micromagnetomator described in detail in Ref. 1. As the source of polarized light we used an LGN-107B helium-neon laser. The samples consisted of epitaxial films of the iron garnet $(BiLu)_3(FeGa)_5O_{12}$ with a uniaxial perpendicular anisotropy, a thickness $t = 10.4$ μm, a strip-domain width $d = 14$ μm, and a saturation magnetization $M_s = 8.8$ G.

Figure 1 illustrates the idea of the experiment. A laser beam is incident at an angle φ on the surface of the sample. The BDW→NDW transition is studied with a transverse orientation of the plane of incidence of the light and the plane of the domain wall (as shown in Fig. 1). An alternating magnetic field $H(f = 14$ Hz) is applied in the plane of the sample perpendicular to the domain wall. The RHW→LHW transition is observed in a field H parallel to the domain wall. In this case the plane of incidence of the light and the plane of the domain wall coincide.

We wish to stress that in the former case the Faraday effect results from the

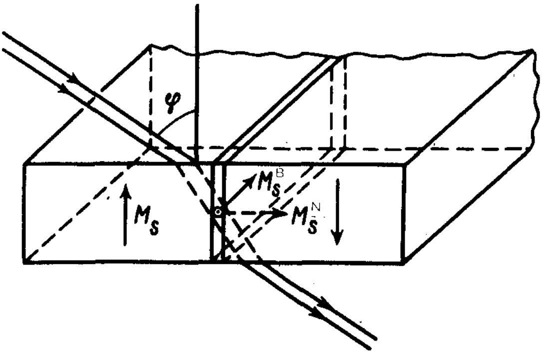

FIG. 1. Layout for detecting the change in the structure of a domain wall in an external magnetic field.

appearance of a Néel component of the magnetization in a thin layer corresponding to the width of the domain wall. In the latter case the Faraday effect in the domain wall results from a field-induced change in the Bloch component of the magnetization. In this configuration, the precision of the alignment of the domain wall parallel to the plane of incidence of the light has an important influence on the magnitude of the Faraday effect in the domain wall. Accordingly, we are reporting the magnetization-reversal curve of the domain wall (RHW→LHW) in a longitudinal field in arbitrary units.

The experimental curves shown below were found by measuring the magnetooptic signal from a part of the test sample with a volume of $1\times10\times t$ μm (the larger dimension corresponds to the plane of the domain wall; t is the thickness of the sample). Side effects (the rotation of the vector M_s in the domains and small oscillations of the domain wall) were eliminated by changing the sign of the angle of incidence of the light.

Figure 2 shows a magnetization-reversal curve of a domain wall which is typical

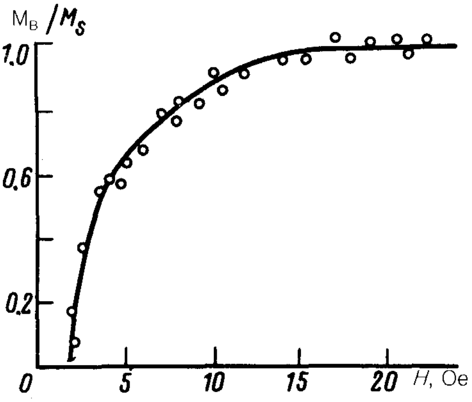

FIG. 2. Magnetization-reversal curve of a domain wall in a longitudinal field.

of the garnet ferrite films which we studied. This curve was measured in a longitudinal field. It was found that in these samples the magnetooptic signal from a domain wall becomes nonzero beginning at $H \sim 2$–4 Oe and remains essentially constant in fields above 14–16 Oe.

A plane domain wall in a film with a perpendicular anisotropy can break up into regions of domain walls of different polarity, separated by vertical Bloch lines.[2] An external magnetic field parallel to the domain wall should cause the regions of the domain wall in which the magnetization is in the same direction as H to increase in size; this increase occurs by virtue of a displacement of vertical Bloch lines. The local magnetization-reversal curve of a domain wall which we measured thus reflects a change in the Bloch component of the magnetization due to a displacement of vertical Bloch lines. The field $H \sim 2$–4 Oe can be taken to be the coercive force of the vertical Bloch lines. We should probably not rule out the possibility of a magnetization reversal of a domain wall as a result of the nucleation and displacement of a horizontal 2π Bloch line in the external magnetic field. The nucleation field for a horizontal Bloch line estimated in accordance with Ref. 3, $H_{2\pi} = 4(2\pi A)^{1/2} t^{-1}$ (A is the exchange parameter), corresponds to ~ 2–3 Oe for the test samples.

Figure 3 shows a magnetization curve of a domain wall (the circles) measured in a transverse magnetic field. We see that in weak fields the Faraday effect increases linearly with H. Above 140 Oe, the Faraday effect changes only slightly. The shape of this curve is evidence that the domain wall is magnetized by virtue of a rotation of the vector M_s away from the Bloch orientation to the Néel orientation.

According to Ref. 3, the static magnetization curve of a domain wall is described in this case by the dashed curve in Fig. 3. The solid curve shows the calculated magnetization in an alternating magnetic field. The difference between the solid and dashed curves at $H > H_{\rm cr}$ ($H_{\rm cr}$ is the field of the BDW→NDW transition) is ex-

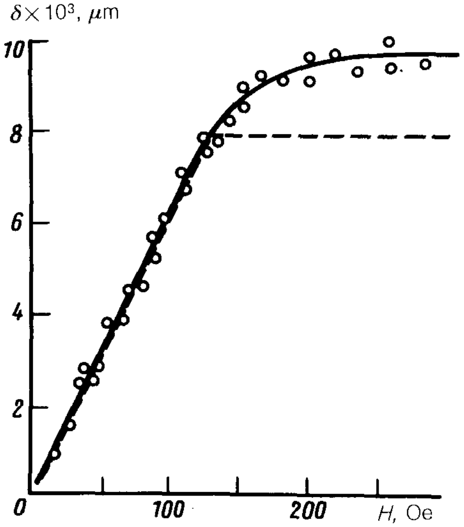

FIG. 3. Magnetization-reversal curve of a domain wall in a transverse field.

plained on the basis that in the measurements in an alternating magnetic field the first harmonic of the useful signal is detected; this harmonic retains its sinusoidal shape up to $H = H_{cr}$. At $H > H_{cr}$ the useful signal becomes trapesoidal and later rectangular, and this fact should be taken into account in the calculation of the amplitude of the first harmonic.

We see from this figure that the experimental points conform well to the solid line. It can thus be assumed that for the test samples we have $H_{cr} = 130$ Oe, which corresponds to $\sim 1.9(8M_s)$. The value found experimentally for H_{cr} is nearly twice the value $H_{cr} = 8M_s$ found on the basis of simple estimates in Ref. 3. It agrees well with the more careful calculations of H_{cr} in Ref. 4. Note also that since we are actually measuring the Faraday effect in a transversely magnetized plate of thickness Δ in the case of the BDW → NDW transition, we can use the relation $\delta = (2/\pi)\delta_0\Delta$ to estimate the width of the Néel domain wall. Here δ_0 is the specific Faraday rotation of the test sample; δ is the measured Faraday effect in the transverse configuration; $\Delta = \pi\sqrt{A/K_{\text{eff}}}$; $K_{\text{eff}} = K(1 + Q^{-1} - \pi H/4H_K)$ (Ref. 3); Q is the quality factor $(Q \gg 1)$; H_K is the anisotropy field; and H is the transverse external field $(H \ll H_K)$. For our sample we have $\delta_0 = 0.81\ \mu\text{m}^{-1}$, $\delta = 0.0079$, and thus $\Delta_{\text{NDW}} \approx 0.15\ \mu$m, in agreement with the calculated value $\Delta = \pi\sqrt{A/K_{\text{eff}}} = 0.12\ \mu$m ($A = 1.4 \times 10^{-7}$ erg/cm, $K = 0.96 \times 10^4$ erg/cm^3).

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