Mass and mobility of a Bloch line at a domain boundary

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We detect a resonance in the shift of the Bloch lines at a domain boundary in a single crystal of yttrium iron garnet and determine their mass and mobility from the characteristics of this resonance.

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It has become more and more obvious in recent years[1] that the structure of the domain boundaries in magnetic materials differs from the idealized scheme of a uniform planar wall, in which the position of the spontaneous magnetization vector $\mathbf{M}_s$ changes only in the direction perpendicular to the boundary. There is direct experimental evidence that the orientation of $\mathbf{M}_s$ within a wall also depends on the other two spatial coordinates both in thin films[1] and in bulk materials.[2,3] In the overwhelming majority of crystals the essential elements of the domain-wall structure are Bloch lines which arise due to the demagnetizing field on the surface of the sample and separate the subdomains in the wall. Without taking these into account it is impossible to describe the mobility of the domain boundaries in uniaxial garnet films, which is the limiting factor in the fast response of the new magnetic memory elements for computers.[4]

Data on the properties of the Bloch lines are necessary, of course, not only for solving the aforementioned technical problem, but also for treating a number of fundamental problems in the magnetism of a wide class of materials. In particular, it was shown in Refs. 5 and 6 that the dynamical properties of 180-degree Bloch walls in bulk samples of multiaxial yttrium iron garnet, for which $K \ll 2\pi M_s^2$ (K is the anisotropy constant), do not agree with the predictions of a theory based on a uniform model of the boundaries, but rather give indications that the Bloch lines play a crucial role in determining the shift of the entire boundary. However, despite the urgency of the problem, the direct experimental determination of the most important characteristics of the Bloch lines, their mobility and mass, has still not been accomplished. Most of the research on the domain-wall dynamics has been done on materials with the CMD (cylindrical magnetic domains) structure, for which there are still difficulties of unknown origin in directly observing the Bloch lines. Studies of yttrium iron garnet single crystals in polarized light[3,5] have opened up the possibility of making such observations. These studies used such observations to find the conditions for the excitation of a resonant shift in the Bloch lines by a sinusoidal magnetic field, in order to determine their mobility and mass.

A single crystal in the form of a wide plate 35 μm thick, containing 180-degree domain boundaries in which $\mathbf{M}_s$ was parallel to the surface of the sample, was placed on the table of a polarization microscope between two coils 1.1 mm in diameter made of fine copper wire. The coils produced a magnetic field perpendicular to the surface of

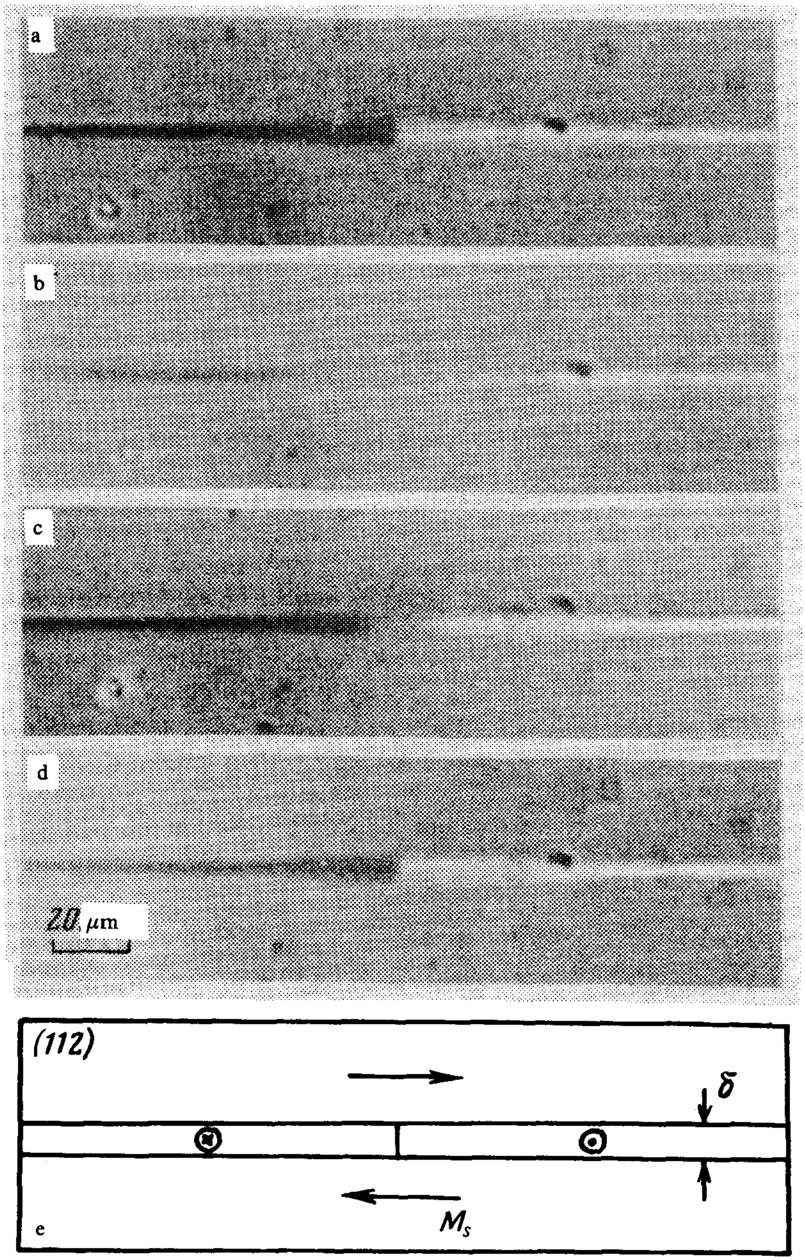

FIG. 1. Shape of a domain boundary having a Bloch line in an alternating field with strength $H_0 = 14\times 10^{-3}$ Oe and angular frequencies ω of: a) $\omega = 0$, $\omega = 225$; b) $\omega = 377$; c) $\omega = 1885$; d) $\omega = 3770$ kHz. e) a schematic diagram of the distribution of magnetization in the sample.

the plate when a current was passed through them. The domain structure (shown schematically in Fig. 1e) was determined by means of the Faraday effect in plane-polarized light. In the absence of external fields a vertical Bloch line was observed in slightly crossed Nicols as a sharp boundary between light and dark subdomains in the wall (Fig. 1a). When an alternating magnetic field of small amplitude H_0 was applied in some interval of frequencies ω, the shift of the Bloch line could be clearly detected by the washout of the contrast of the transition region between subdomains (Fig. 1b, 1c). As the frequency ω was increased further, the amplitude of the shift of the Bloch line decreased to where it could no longer be resolved in the microscope (Fig. 1d). The shifts in Bloch line as a function of ω at $H_0 = 0.014$ Oe, as measured by the size of the region in which the contrast was washed out, is shown in Fig. 2. This function has a resonant character. We note that the shift x due to a constant field H_0 is also less than the wavelength of visible light.

As in the case of the domain boundary, the mobility of the Bloch line can be described by the equation $m\ddot{x} + \beta\dot{x} + ax = 2M_s d\delta H_0 \cos\omega t$, where β is the effective viscosity, which is inversely proportional to the mobility μ of the Bloch line $(\beta = 2M_s/\mu)$, d is the thickness of the plate, δ is the width of the boundary, and t is the time. The stiffness coefficient a due to the demagnetizing field caused by magnetic poles on the surface of the crystal at the point where the surface intersects the Bloch wall can easily be determined by additional experiments on the dependence of x on H_0 during quasistatic magnetization of the boundary. The resonant frequency ω_p of the shift and the maximum displacement x_p give the expressions $\omega_p = (a/m - \beta^2/2\,m^2)^{1/2}$ and $x_p = 2M_s d\delta H_0/\omega'\beta$, where $\omega' = (a/m - \beta^2/4\,m^2)^{1/2}$, from which one can determine m and β. For the case shown in Fig. 2 the calculations give the values $m = 2.1\times10^{-10}$ g/cm and $\beta = 5.9\times10^{-7}$ g/sec·cm. This value of β is substantially larger than the value calculated from the damping parameter in the Landau-Lifshits

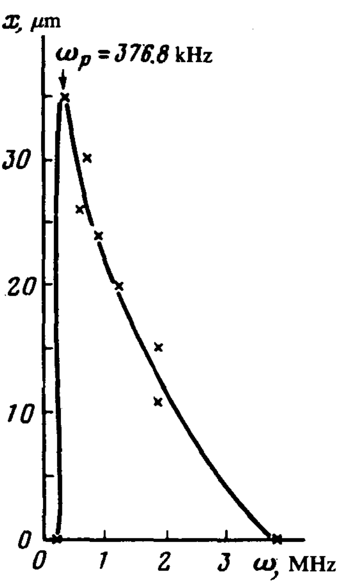

FIG. 2. Shift x of the Bloch line as a function of the frequency ω of the external magnetic field. $H_0 = 0.014$ Oe; $a = 0.19$ g/sec^2·cm

equation as determined from ferromagnetic resonance experiments, but not as much larger as in the case of the motion of the entire 180-degree domain boundary.[6] The measured value of the mass of the Bloch line agrees well in order of magnitude with the value calculated with the data of Ref. 6 on the mass m_w of the entire domain wall (obtained by dividing m_w by the number of Bloch lines in the wall).

The scatter of the m and β values determined for different vertical Bloch lines is relatively large: $\sim \pm 25\%$. The shape of the experimental resonance curve differs from the theoretical. The frequency dependence of the shift of the line for $\omega > \omega_p$ turns out to be smoother. These facts could be due to the effect of lattice defects[3] on such characteristics of the domain structure as the size of the subdomains in a wall (and, hence a), the coercive force necessary for motion of the Bloch line, etc. They could also be due to a dynamical change in the structure of the Bloch wall (the motion and nucleation of Bloch points, affecting m) and the interaction of neighboring Bloch lines.

In conclusion, we note that the structure of the Bloch lines in the crystal studied here differs substantially from that studied theoretically in Ref. 4 for magnetically uniaxial materials. There has been no rigorous theoretical treatment of the experimental situation described in this letter.

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