# Magnetic resonance of vertical Bloch lines in garnet ferrite films

V. G. Pokazan'ev, Yu. I. Yalyshev, K. I. Lukash, and G. R. Murashev
*Ural Electromechanical Institute of Railroad Transportation Engineers*

(Submitted 30 March 1984; resubmitted 15 November 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **41**, No. 1, 21–23 (10 January 1985)

A signal corresponding to a resonance of vertical Bloch lines has been found in a thin garnet ferrite film. It thus becomes possible to study the internal structure of a domain wall and controlled conversions of this structure.

The dynamic properties of domain walls in a thin garnet ferrite film with an anisotropy perpendicular to its plane have been linked with structural features of the domain wall, structural changes, and the dynamics of structural elements, i.e., ultimately with the state of the domain wall. There are several ways to change the state of a straight domain wall (the only type we will consider here); in particular, this can be done by applying a static magnetic field $H_p$ in the plane of the film and parallel to the domain wall. Depending on the strength of this field, the domain wall, as was shown in Ref. 1, can be in one of the states occupying intermediate positions between two extreme states corresponding to the case in which the wall is completely polarized (all the spins at the center of the domain wall are oriented in the same direction) and demagnetized. The most likely representation of the domain wall in the latter case is a wall broken up into subdomains (Fig. 1a) with transitional regions ("vertical Bloch lines") in which the magnetization changes direction. The equilibrium distribution of vertical Bloch lines along a demagnetized domain wall is determined by the balance between the magnetostatic and exchange interactions. These interactions also determine the frequency ($\Omega_0$) of the natural oscillation modes of the vertical Bloch lines along a domain wall when these lines diverge from their equilibrium position.

The magnetostatic and dynamic properties of a polarized domain wall are different from a domain wall with vertical Bloch lines. A complete picture of the domain

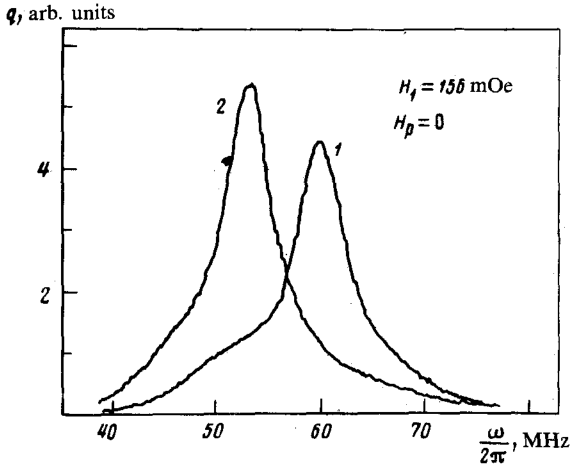

FIG. 1. Shift of the resonant frequency of a demagnetized domain wall caused by the field $H_2$. 1—$H_2 = 0$; 2—$H_2 = 800$ mOe.

wall can be obtained by solving the Landau-Lifshitz equation (see Ref. 2, for example). Here we will report only those results that are required for explaining the experiments discussed below. If a uniform alternating magnetic field $H_1 \cos\omega t$ is applied to a film, in the direction perpendicular to its plane, we would expect no special features of any sort in the motion of the polarized walls: They execute forced translational oscillations, which become resonant oscillations when the frequency $\omega$ coincides with the frequency $(\omega_0')$ of the natural oscillations.[3] The motion of walls with vertical Bloch lines is far more complicated in this case. In addition to translational oscillations, bending modes may be excited. The resonant frequency of the lowest oscillation mode is higher than that of a polarized domain wall and depends on whether the vertical Bloch lines are at rest or are moving along the wall. If the vertical Bloch lines are executing resonant oscillations at the frequency $\Omega_0$ around their equilibrium position under the influence of the alternating magnetic field $H_2 \cos \Omega t$, which is oscillating along the domain wall, then the oscillatory motion of the domain wall will appear as if its effective mass were increased.[2] Consequently, there is a downward shift of the resonant frequency of the wall oscillations, and this shift can serve as the physical basis for an experimental detection of a resonance of vertical Bloch lines and an experimental detection of their dynamic state.

The present experiments were carried out in a $(\mathrm{YSm})_3(\mathrm{GaFe})_5 \cdot \mathrm{O}_{12}$ film 2.1 $\mu$m thick with a $g$-factor $\sim 1.5$ and with $4\pi M_s = 280$ G, where $M_s$ is the saturation magnetization. The polarized and demagnetized states of the domain wall were produced by the method of Refs. 1 and 3. The inset in Fig. 2 shows the field geometry. The oscillations of the walls of the strip domains are observed by means of the Faraday effect.[1]

For observation of the effect of the motion of the vertical Bloch lines on the oscillations of the domain wall, the field $H_2$ is oriented along the direction of the wall. In this case the energy of the interaction of the spins of the wall with the field $H_2$ is of the form $H_2 \cos \Omega t \cos \phi(x)$, where $\phi(x)$ is the angle between the spin and the $x$ axis, which runs along the domain wall. The field $H_2$ affects only the spins in a vertical Bloch line. Figure 2 shows signals with resonances of domain walls with vertical Bloch lines, in the absence of the field $H_2$ (curve 1) and in the presence of $H_2$ (curve 2). The field $H_2$ causes a downward shift of the resonant frequency $(\omega_0)$ of the wall with the vertical Bloch lines. The experiments show that this shift is essentially absent at all frequencies $(\Omega)$ of the field $H_2$ except in a narrow interval ($\sim 5$ MHz) near the frequency $\Omega_0/2\pi = 53$ MHz. At this frequency, we observe a maximum in the shift of the frequency $\omega_0$. Curve 2 in Fig. 1 shows a signal with a resonance of a domain wall in the case $\Omega = \Omega_0$. There is a definite resonant dependence of the frequency $\omega_0$ of the resonant oscillations of the domain wall on the frequency of the second field, $\Omega$, which can, under these experimental conditions, affect the vertical Bloch lines and excite their oscillations. This resonance of the vertical Bloch lines and its effect on the oscillations of the domain walls can be seen more clearly by altering the experimental arrangement slightly. For example, if the frequency $(\omega)$ of the field $H_1$ is chosen slightly to the right of the resonant value $\omega_0/2\pi = 60$ MHz in the absence of $H_2$, and if the change in the amplitude of the signal corresponding to oscillations of the domain wall at this frequency is followed as the frequency $(\Omega)$ of the second field is swept (the second field causes the forced oscillations of the vertical Bloch lines), then as $\Omega$ ap-

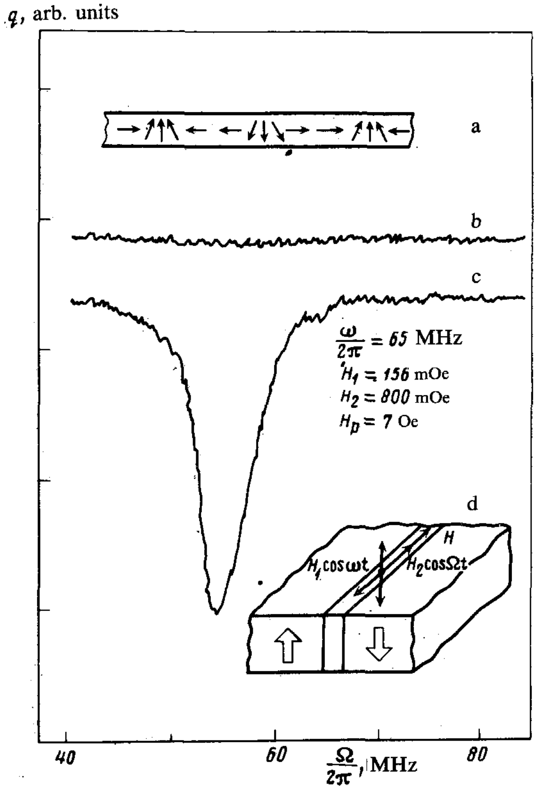

FIG. 2. Signal showing a resonance of vertical Bloch lines.

proaches the resonant value $\Omega_0$, the signal corresponding to the oscillations of the domain wall will decrease (since curve 1 begins to move to the left), go through a minimum, and then begin to increase again to its original value. Figure 1c shows a signal corresponding to oscillations of the domain wall at the frequency $\omega/2\pi = 65$ MHz. This is a resonant curve; the minimum corresponds to $\Omega/2\pi = 53$ MHz. If we start to the left of the frequency $\omega_0/2\pi = 60$ MHz, we would expect that a scanning of the frequency $\Omega$ would cause the oscillation signals to increase, peak at the resonant frequency of the vertical Bloch lines, and to decay subsequently. We did in fact observe this pattern, although we are not reproducing it here.

Figure 1b shows the resonant oscillations of a polarized wall at the frequency $\omega_0'/2\pi = 57$ MHz as the frequency $\Omega$ is swept. We see that the height of the signal does not change; i.e., the field $H_2$ has no effect on the polarized wall, in agreement with our understanding of the structure of polarized and demagnetized walls and the effect of external fields on them.

In summary, these results show that the behavior of the domain walls of straight domains is largely determined by the structure of a domain wall, the structure of the vertical Bloch lines, and information about this state and other aspects of the behavior of domain walls can be obtained from the resonance of vertical Bloch lines. This resonance appears to us to be the only tool available at present for studying the structure and behavior of domain walls in the magnetic fields of thin films.

[1] V. G. Pokazan'ev, Yu. I. Yalyshev, and K. I. Lukash, Pis'ma Zh. Tekh. Fiz. **10**, 666 (1984) [Sov. Tech. Phys. Lett. **10** (1984)].
[2] A. P. Malozemoff and J. C. Slonczewski, Magnetic Domain Walls in Bubble Materials, Applied Solid State Science, Supplement I, 1979 (Russ. transl. Mir. Moscow, 1982).
[3] Yu. I. Yalyshev, K. I. Lukash, and V. G. Pokazan'ev, Fiz. Tverd. Tela (Leningrad) **26**, 1549 (1984) [Sov. Phys. Solid State **26**, 943 (1984)].

Translated by Dave Parsons
Edited by S. J. Amoretty