Ferromagnetic resonance in closing domains in two-layer garnet films

V. F. Shkar', I. M. Makmak, and V. V. Petrenko
Donetsk State University, 340055, Donetsk, The Ukraine

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Magnetic resonances have been detected in closing domains in a sublayer under a main layer. These resonances have been studied. The domains result from a domain structure in the main layer with an easy magnetization axis. The orientation of the magnetic moments in each of two groups of closing domains has been determined.

An interaction between magnetic layers gives rise to distinctive features in the spin-wave resonance[1] for the saturated state of an iron garnet film. In particular, a repulsion of ferromagnetic-resonance lines occurs. The interaction of magnetic domains in a single-layer film may also give rise to a repulsion of the modes of a domain ferromagnetic resonance.[2] In this letter we are reporting a ferromagnetic-resonance study of two-layer films with a domain structure. The films were grown by liquid-phase epitaxy[3] on substrates of (111) gallium-gadolinium garnet. The first layer grown on the substrate was $(Y, Gd, La)_3(Fe,Ga)_5O_{12}$, with a thickness $d_1 \approx 0.05$ μm and a saturation magnetization $4\pi M_1 = 380$ Hz. The second layer was $(Y, Eu, Tm, Lu)_3(Fe,Mn,Ga)_5O_{12}$, with a thickness $d_2 = 2.85$ μm and $4\pi M = 148$ Hz. The exchange constants in the layers were $A_1 = 2.5 \times 10^{-7}$ erg/cm and $A_2 = 2 \times 10^{-7}$ erg/cm. The gyromagnetic ratios were $\gamma_1 = 1.76 \times 10^{-7}$ $s^{-1} \cdot Oe^{-1}$ and $\gamma_2 = 1.47 \times 10^7$ $s^{-1} \cdot Oe^{-1}$. The damping constants were $\alpha_1 = 8 \times 10^{-3}$ and $\alpha_2 = 2.7 \times 10^{-2}$. The constants of the uniaxial magnetic anisotropy were $K_1^u = 0$ and $K_2^u = 7.7 \times 10^3$ erg/cm^3. The constants of the cubic magnetic anisotropy were $K_1 = 1.1 \times 10^3$ erg/cm^3 and $K_2 = 4.1 \times 10^2$ erg/cm^3. The collapse field of the domain structure in the main (second) layer was $H_0 = 56$ Oe. The in-plane saturation field for the main layer was $H_{\parallel} = 1060$ Oe.

The experiments were carried out over the frequency range 0.4–10.5 GHz at room temperature. When the field was directed in the plane of the film, it was possible to observe either one or two absorption lines at a frequency of 1.2 GHz, depending on the azimuthal angle φ. Figure 1 shows the resonant fields of these lines as a function of φ. When the field was directed along a $\langle 112 \rangle$ axis, the distance between the lines was at a maximum; when the field was along a $\langle 110 \rangle$ axis, the lines coincided and were perceived as a single line in the experiments. We also see that each of the $H_p(\varphi)$ curves has three minima and three maxima. A minimum of one curve coincides with a maximum of the other. When the main layer is etched down from a thickness of 2.85 μm to 1 μm, no change is caused in the shape of the $H_p(\varphi)$ curves or in the line intensities. This fact, combined with the results on a ferromagnetic resonance of the main layer at higher frequencies (5–10 GHz), is evidence that the resonances observed at 1.2 GHz are excited in the sublayer.

We also studied the behavior of the resonant fields of these lines as a function of the polar angle θ, at two values of φ. In the first case, the angle φ was chosen such that the distance along the field scale between the lines was at a maximum (with $\theta = 0$). In the second case, this angle was chosen in such a way that the lines coincided. The results of these measurements (at 1.2 GHz) are shown in Fig. 1. In the first case, the two lines were of identical intensity in the original state ($\theta = 0$). When θ was varied in the negative direction, the low-field line intensified, while the high-field line shrank, essentially disappearing at $\theta = -7°$. When θ was varied in the positive direction, the opposite effects were observed: The high-field line intensified, and the low-field line shrank, disappearing at $\theta = 11°$. The resonant fields of these lines varied only negligibly in this angular interval. In the second case, a single ferromagnetic-resonance line was observed over the entire range of θ.

The set of facts established in these experiments can be explained on the basis of a simple model of closing domains in a two-layer structure. The basis idea here is that a domain structure exists in the main layer over the range of in-plane fields 0–1060 Oe,

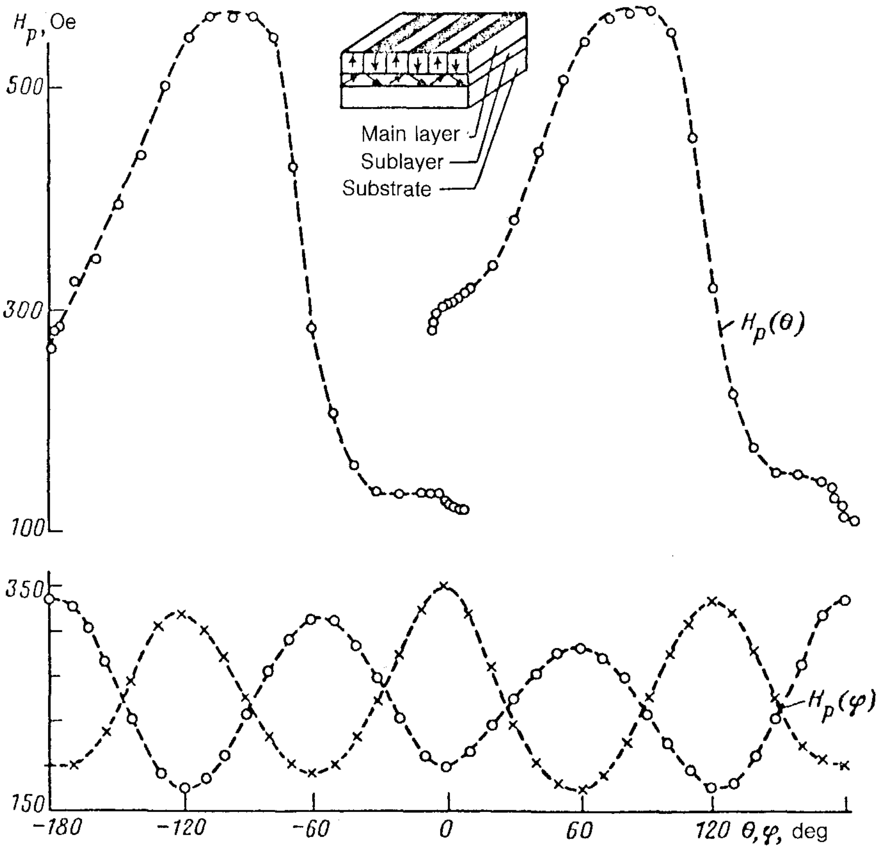

FIG. 1. The resonant fields H_p versus the polar angle θ and the azimuthal angle φ.

and closing domains arise in the sublayer (see the inset in Fig. 1). When the external magnetic field is zero, the magnetization vector in the domains of the main layer is along the normal to the plane of the film, since the uniaxial-anisotropy field is stronger than the demagnetizing field of the sample. In polarized light, these domains are seen as black domains (the magnetization vector is pointed downward) and white domains (upward). The inclination of the magnetic moments in the closing domains is determined by the cubic-anisotropy field (the uniaxial anisotropy is zero), by the demagnetizing field, and by the fringing of the nearest domain in the main layer. We assume that there are two groups of closing domains: one under the black domains and one under the white ones. In general, these different groups of domains will have different inclinations of the magnetic moment in a weak in-plane magnetic field [because of the symmetry of the cubic anisotropy in the (111) film]. Only if the field is directed along a $\langle 110\rangle$ axis (of which there are six in the plane of the film) will the angles be equal. If the field is instead directed along a $\langle 112\rangle$ axis (of which there are, again, six in the plane of the film), the difference in inclination angles will be at a maximum. When a ferromagnetic resonance is excited in such domains, a line will be observed from each group, and the behavior of the resonant fields will be like that shown in Fig. 1. If the field is rotated through an angle θ, a normal component appears. This normal component alters the relation between the black and white domains. When this component reaches the collapse field of the domains in the main layer, the closing domains disappear. Consequently, one of the ferromagnetic-resonance lines disappears.

We can estimate the polar angle θ of the magnetic moments of the closing domains in the following way. At 1.2 GHz the resonant field (an in-plane field, along a $\langle 110\rangle$ axis) is 240 Oe, and closing domains exist in the sublayer. At 10.5 GHz, the resonant field is 3450 Oe, and the sublayer is uniformly magnetized. The resonant fields directed normal to the film for these frequencies are 640 Oe and 4020 Oe, respectively, and the substrate is again magnetized to saturation. It follows that, if the sublayer were uniformly magnetized in an in-plane field at a frequency of 1.2 GHz, then the resonant field would have been lower by 170 Oe. In order to increase the resonant field by 170 Oe, it is necessary, at 10.5 GHz, to move the angle θ to a point 27° out of the plane of the film. This is the resonant value of the polar angle of the closing domains when the in-plane field of 240 Oe is directed along a $\langle 110\rangle$ axis. If the field is directed along a $\langle 112\rangle$ axis, we find angles of 16° and 38° for the two groups of domains from the curve of $H_p(\varphi)$ at a frequency of 1.2 GHz.

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