FERROMAGNETIC RESONANCE IN FILMS WITH FERRO-ANTIFERROMAGNETIC INTERACTION

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An experimental investigation was made of ferromagnetic resonance (FMR) in thin Mn—FeNi films, subjected to thermomagnetic treatment and possessing unidirectional anisotropy. An asymmetry of the FMR peaks relative to zero along the field axis, an asymmetry of the FMR line width relative to the resonance field, and a difference between the absorption peak intensities when the magnetization was directed along or opposite the unidirectional anisotropy, were observed. The effects discovered were interpreted on the basis of a previously proposed model for magnetization in films with the ferro-antiferromagnetic interaction.

It is known that unidirectional anisotropy appears when ferro- and antiferromagnetic films are placed near to one another. Thin ferromagnetic films with the ferro-antiferromagnetic interaction can be obtained by subjecting a two-layer Mn—FeNi film system to thermomagnetic annealing.[1] Unidirectional anisotropy of such films is manifested by a displacement of the hysteresis loop along the field axis (Fig. 1), an increase of the coercive force H_c, etc.,[2] which indicates the special nature of the magnetization processes in such films. The process of magnetization of "unidirectional" films has been investigated already[3] by the high-frequency susceptibility method, and a model has been suggested, explaining the experimental susceptibility curves. According to this model, the magnetization of a sample along the direction opposite to the unidirectional anisotropy produces a transition layer in a film in which a helical configuration of the spin system across the film thickness is observed. Naturally, the presence of such a layer should affect the high-frequency behavior of films (pulse magnetization, ferromagnetic resonance).

We are reporting the results of an investigation of ferromagnetic resonance (FMR) in films with unidirectional anisotropy. The thickness of the ferromagnetic layer in the investigated samples was ~1000 Å, the displacement field $H_d \approx 4-10$ Oe, and the coercive force $H_c \approx 3-6$ Oe. The FMR in these unidirectionally anisotropic films was observed in the frequency range 1.3–2.3 GHz. A block diagram of the apparatus is shown in Fig. 2.

Microwave power from an oscillator 1 was supplied to a channel, consisting of attenuators 2 and 5, a measuring line 3, and a strip system 4 carrying the film being investigated. The detected signal 6 was observed either on the screen of an oscillograph 7 or recorded on the

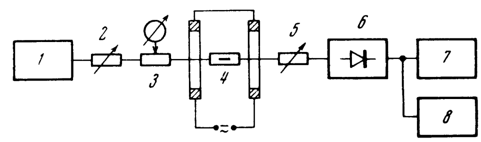

FIG.2. Block diagram of the apparatus.

chart of a two-coordinate recorder 8. Helmholtz coils were used to produce a constant or alternating (50 Hz) field of up to 300 Oe intensity in the plane of the film.

Figure 3 shows the FMR curves for a film with unidirectional anisotropy, recorded at 1.3 GHz for various orientations of a constant field relative to the unidirectional anisotropy direction. For angles α = 90 and 270°, the shape of the FMR curves is similar to the curves obtained for films with uniaxial anisotropy, but when α = 0 and 180°, the effect of the unidirectional anisotropy is manifested by an asymmetry of the positions of the FMR peaks relative to zero along the field axis, an asymmetry of the absorption line width for α = 180°, a difference between the heights of the absorption peaks for a film magnetized along and opposite to the direction of unidirectional anisotropy, and a hysteresis of the

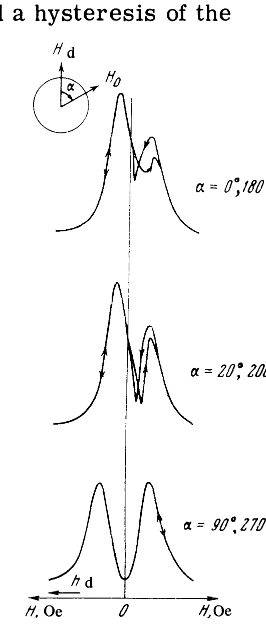

FIG. 3. FMR absorption curves: H_d represents the unidirectional anisotropy vector; H_0 is the constant field. The angle α is measured from the direction of H_d. The peaks on the left-hand side correspond to angles α = 0, 20, and 90°; those on the right-hand side correspond to α = 180, 200, and 270°.

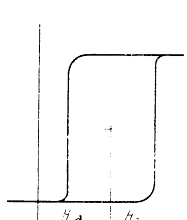

FIG. 1. Hysteresis loop of films with unidirectional anisotropy.

right-hand side absorption peaks for opposite directions of the magnetization.

The shape of the FMR curve (α = 180°) exhibits sudden changes in fields H_c. The values of H_c, deduced from the FMR curves and from the hysteresis loop, are equal.

Figure 4a shows the absorption curves for α = 0 and 180° at various frequencies. It is evident from this figure that the asymmetry of the FMR peak amplitudes decreases with increasing frequency. Figure 4b shows the dependence of $\Delta\chi/\chi$ on the resonance frequency, which represents the degree of the asymmetry of the FMR peaks.

The observed anomalies of the FMR of the investigated films are explained by the fact that the magnetization of the film along the direction opposite to the unidirectional anisotropy produces a transition layer with a helical configuration of the spin system.[3] The presence of the magnetization "ripples" may twist the spin system helices in the transition layer in opposite senses (Fig. 5a).

The formation of the transition layer reduces the effective thickness of the film participating in the uniform precession of the magnetization, which should reduce the signal at the detector output. When the resonance field applied at an angle α = 180° increases with increasing frequency, the thickness of the transition layer decreases[3] and this increases the effective film thickness and consequently enhances the resonance peak. This explains the amplitude asymmetry of the FMR curves and the frequency dependence of this asymmetry.

When the film is magnetized along a direction making a small angle (α = 190°) with the unidirectional anisotropy, the configuration of the transition layer (Fig. 5b) differs from that just described because the direction of twist of the helices is now the same throughout the film. Consequently, the rotation of the spins toward the external field direction, when that field is increased, is more rapid than in the preceding case (in the preceding case the presence of strong fringing fields between the neighboring spin helices impedes the magnetization process). This results in a decrease of the amplitude asymmetry of the FMR peaks at lower frequencies (curve 2 in Fig. 4b). A hysteresis of the transition layer, reported in[3], is the cause of the hysteresis of the resonance peaks on the right-hand side (such as peak d in Fig. 4a) on the application of an external field directed opposite to the unidirectional anisotropy (α = 180°).

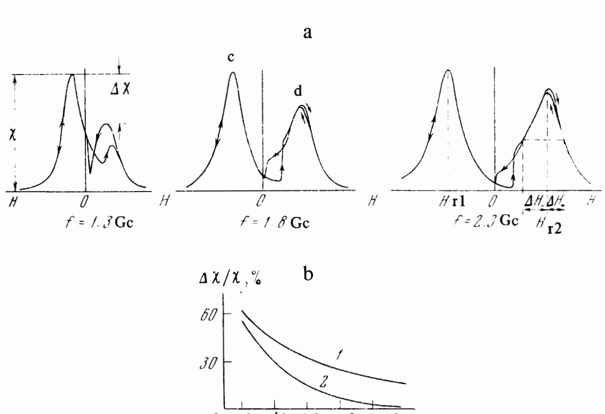

FIG. 4. a) Absorption curves at various frequencies; b) frequency dependence of $\Delta\chi/\chi$: 1) α = 180°; 2) α = 190°.

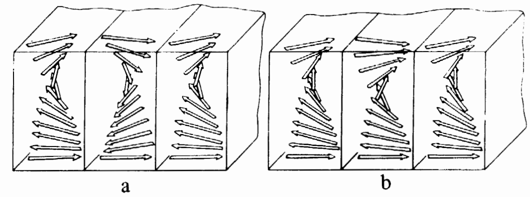

FIG. 5. Configuration of the spin system in a transition layer during the magnetization of films with unidirectional anisotropy. The two lowest layers of spins represent the upper boundary of the antiferromagnet and the others represent the ferromagnetic layer; a) magnetization along the unidirectional anisotropy direction; b) magnetization along the direction making a small angle with unidirectional anisotropy direction.

The presence, in the transition layer, of spins oriented at various angles to a high-frequency magnetic field should increase the FMR line width (for α = 180°). Since the thickness of the transition layer decreases with increasing field intensity, the line broadening effect should decrease in stronger fields and this should result in an asymmetry of the FMR line width (for peaks such as d in Fig. 4a): $\Delta H_- > \Delta H_+$.

Had it been possible to describe the effect of the unidirectional anisotropy by a constant field H_d (Fig. 1), acting along an easy magnetization axis and independent of the external field and, consequently, of the magnetic state of the film, the resonance fields H_{r1} and H_{r2} of peaks c and d in Fig. 4a would have differed by an amount $2H_d$. The results of measurements of the field H_d (deduced from the hysteresis loop) and of $H_{r2} - H_{r1}$ for four typical samples are tabulated below.

Sample No,	H_c, Oe	H_d, Oe	$H_{r2} - H_{r1}$, Oe (f = 1.3 GHz)	$H_{r2} - H_{r1}$, Oe (f = 2.3 GHz)
169—1	5,2	9,2	8,2±0,5	1,5±1
170—6	5	6,3	5,5±0,5	4±1
168—8	4,8	5	4,8±0,5	2±1
168—5	4.2	4	4,5±0,5	4±1

It is evident from the table that $H_{r2} - H_{r1} < 2H_d$ for all samples and the value of $H_{r2} - H_{r1}$ decreases with increasing frequency. The fact that the FMR peaks are shifted by an amount smaller than $2H_d$ confirms the assumption of a complex change in the effective internal field, due to the ferro-antiferromagnetic interaction, on the applied external field.[3]

Thus, the observed FMR anomalies of annealed Mn—FeNi films can be explained qualitatively on the basis of the model proposed in[3].

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