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TEMPERATURE DEPENDENCE OF FERROMAGNETIC RESONANCE IN FILMS WITH UNIDIRECTIONAL ANISOTROPY

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Results of an experimental investigation of the effect of temperature on the high-frequency susceptibility and the FMR parameters in thin Mn–FeNi films subjected to thermomagnetic treatment and possessing unidirectional anisotropy are presented. The measurements were made between room temperature and the Néel point of the antiferromagnetic layer produced during mutual diffusion of manganese and permalloy. The susceptibility and FMR curves are found to assume the shape typical of uniaxial films upon transition through the Néel point. It is suggested on the basis of the results obtained that the high-frequency behavior of such films is due to exchange ferro-antiferromagnetic interaction.

THE presence of exchange (unidirectional) anisotropy in films of Mn-FeNi subjected to thermomagnetic treatment leads to the appearance of a whole series of new properties in film samples.[1-4] The high-frequency properties of such films also possess a number of peculiarities[5,6] that are absent in usual films with uniaxial anisotropy. A change in the static parameters of such films with temperature was observed in [7].

This paper presents the results of an investigation of the effect of temperature on the high-frequency susceptibility and FMR in the interval from room temperature to the Néel point of antiferromagnetic Mn–FeNi. Since the Néel point of this antiferromagnet is lower than the Curie temperature of the ferromagnetic layer,[7] temperature measurements make it possible to trace the change in the high-frequency and static properties of the films with the gradual decrease in exchange anisotropy until it completely disappears. Thus, it is possible to isolate the effects arising as a consequence of ferro-antiferromagnetic interaction.

The experiment was performed on films obtained by the methods described in [2] and coated with a layer of SiO to prevent oxidation. Such a protective coating allows high-temperature measurements at atmospheric pressure. In order to reduce the effect of thermomagnetic annealing at the time of the experiment, we used films obtained as the result of long annealing, and the reversing field was applied along the easy axis and turned on only for the measurements.

Figure 1 gives the susceptibility curves (f = 90 MHz) at various temperatures taken for a typical film with unidirectional anisotropy. Raising the temperature to 170–190° C did not significantly affect the shape of the susceptibility curves.[1] However, upon further increase in temperature, the behavior of the susceptibility changes. If in fields greater than H_c (the right branch of the curves) the susceptibility depended weakly on field and had a small value, then beginning at about 200° C a rapid increase in χ is seen on approach to the field H_c in the right branch of the curves. At about this same temperature, H_d begins to decrease, which is evidence of decreasing exchange anisotropy. This in turn leads to a decrease in the thickness of the transition layer formed after reversing the magnetization of the film opposite to the unidirectional anisotropy.[5,6] It is just because of this that one sees the increase in susceptibility χ in the right branch of the curves. For typical films with unidirectional anisotropy at 240–350° C, the susceptibility curves assume the shape characteristic of ordinary uniaxial films.[8] The coercive force H_c of the films then reaches its minimum value, and the displacement field H_d becomes equal to zero. This is evidence of the disappearance of exchange interaction and, consequently, for the attainment of the Néel point of the antiferromagnetic layer. The transition of the curves $\chi(H)$ at the Néel temperature to the form typical for uniaxial films shows that the specific behavior of these curves below the Néel point is really due to exchange anisotropy.

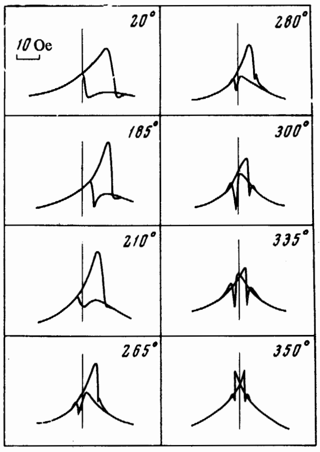

FIG. 1. Susceptibility curves for remagnetization of a film along the axis of unidirectional anisotropy at various temperatures, °C.

The behavior of the functions $H_d(T)$ and $H_c(T)$, as measured from the curves of $\chi(H)$ at various temperatures, is shown in Fig. 2. The results obtained agree well with the measurements of these functions taken from hysteresis loops.[7]

To investigate the effect of temperature on the FMR

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[1] This behavior of the $\chi(H)$ curves is explained in [5].

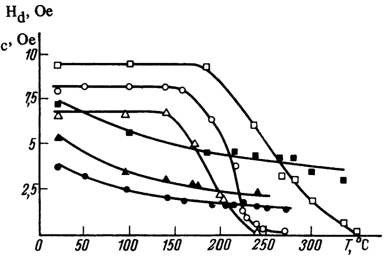

FIG. 2

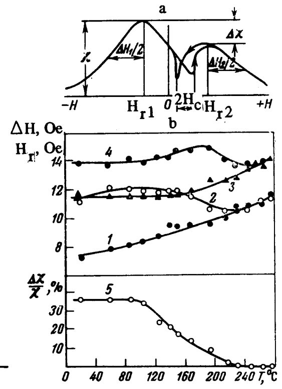

FIG. 3

FIG. 2. Temperature dependence of H_d (□, ○, △) and H_c (■, ●, ▲); □, ■ – film 1 (the same one as in Fig. 1); ○, ● – film 2; △, ▲ – film 3.

FIG. 3. Resonant absorption curve (f = 1200 MHz) in an external field directed along (-H) and opposite to (+H) the unidirectional anisotropy (a), and the temperature behavior of the resonance parameters (b).

parameters to films with unidirectional anisotropy, one needs to choose a relatively low frequency at which the effects associated with unidirectional anisotropy are still large.[6] With this requirement in mind, we chose a frequency in the range 1200–1600 MHz. At such frequencies it is possible, from the FMR curves recorded at different temperatures, not only to trace out the temperature dependence of the resonance field, the FMR line width, and the magnitude of the susceptibility, but also to measure the functions $H_c(T)$ and $H_d(T)$, since at these frequencies one sees sharp disruptions in the behavior of the FMR curves in the fields H_c.[6]

The temperature behavior of the resonance parameters for a typical sample with unidirectional anisotropy at 1200 MHz is shown in Fig. 3b (for symbols, see Fig. 3a).

The resonance field H_{r1} during magnetization of the film in the direction of unidirectional anisotropy increases monotonically with increasing temperature (curve 1), as is also observed in ordinary uniaxial films.[2)]

A more complex temperature dependence is obtained when the film is magnetized opposite to the unidirectional anisotropy (curve 2). At room temperature the resonance field H_{r2} for this peak is somewhat larger than the resonance field H_{r1} for magnetization of the film in the direction of the unidirectional anisotropy.[6] For the given sample the difference $H_{r2} - H_{r1}$ is about 4 Oe.

When the temperature is raised to approximately 100° C, the behavior of $H_{r2}(T)$ is like that of $H_{r1}(T)$. Since the magnitude of the exchange anisotropy, which is characterized by the displacement field H_d, remains approximately constant in this temperature interval (see Fig. 2), the difference $H_{r2} - H_{r1}$ likewise does not change (curves 1 and 2 run parallel). Further temperature increase leads to a decrease in exchange anisotropy and the difference between the resonance fields H_{r2} and H_{r1} contracts because of the decrease in H_{r2}. The decrease in H_{r2} persists up to temperatures of the order 240–250°C (the region of the Néel point). On passage through the Néel point the resonance fields H_{r1} and H_{r2} equalize, which is evidence for the disappearance of the unidirectional anisotropy.

The behavior of curve 3, which characterizes the "half-width" of the resonance peak when the film is magnetized in the direction of unidirectional anisotropy, is analogous to the behavior of the similar dependence for uniaxial permalloy films: up to about 140° C the line width does not change; upon further heating of the sample, there is an increase in $\Delta H_1/2$.

The behavior of the curve for $\Delta H_2/2$ (curve 4) up to about 160–180°C resembles that of curve 3 with the only difference that $\Delta H_2/2 > \Delta H_1/2$. This difference, as was pointed out in [6], is due to the presence of a transition spiral layer when the film is magnetized opposite to the unidirectional anisotropy.[5] The decrease in magnitude of the unidirectional anisotropy as the temperature is increased further leads to a reduction in the thickness of the transition layer in the ferromagnet and, consequently, to a decrease in the "half-width" of the line $\Delta H_2/2$. On passage through the Néel point the exchange anisotropy disappears, and so, therefore, does the transition layer. The magnitude of $\Delta H_2/2$ becomes equal to $\Delta H_1/2$.

The disappearance of the transition spiral layer also explains the observed dependence $\Delta\chi/\chi = f(T)$, which characterizes the asymmetry of the resonance peaks with respect to absorption intensity (Fig. 3b, curve 5). As is seen, this asymmetry disappears on going through the Néel point.

Thus, the temperature dependence of the high-frequency susceptibility and of the resonance parameters of films with unidirectional anisotropy confirms that the observed peculiarities of the high-frequency behavior of such films (the specific shape of the $\chi(H)$ curves,[5] the displacement of the susceptibility and FMR curves in field, the asymmetry of the line widths and of the intensities of the absorption curves upon magnetization of the film parallel and antiparallel to the unidirectional anisotropy[6]) are due to the presence of an exchange ferro-antiferromagnetic interaction. All of these peculiarities disappear when the sample is heated to the Néel point (240–250° C).

[2)] Control experiments on the observation of the temperature dependence of the FMR parameters were performed on permalloy films of composition 80% Ni, 20% Fe that were deposited in vacuum on a glass substrate.

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