Ferromagnetic relaxation anomaly in the transition to a spin-glass-type state

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An anomalous behavior of the ferromagnetic-resonance line width and of the Landau-Lifshitz relaxation frequency was detected in a disordered $Ni_{75}Mn_{18}Fe_7$ alloy in the transition from the ferromagnetic state to a spin-glass-type state at $T_0 \simeq 60$ K.

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It was shown in several papers that a double magnetic transition—from the paramagnetic state to the ferromagnetic state at T_c and to a spin-glass-type (SGT) state at a lower temperature T_0—can occur in disordered systems when a ferromagnetic interaction competes with an antiferromagnetic interaction.[1] Theoretical studies of the dynamics of spin waves in disordered, noncollinear, magnetic materials (including "pure" spin glasses) have shown that the spin waves in such systems, especially magnons with wave vectors $K \approx 0$, are well defined but weakly relaxing excitations.[2] The goal of this paper is to study the influence of the transition to the SGT state on

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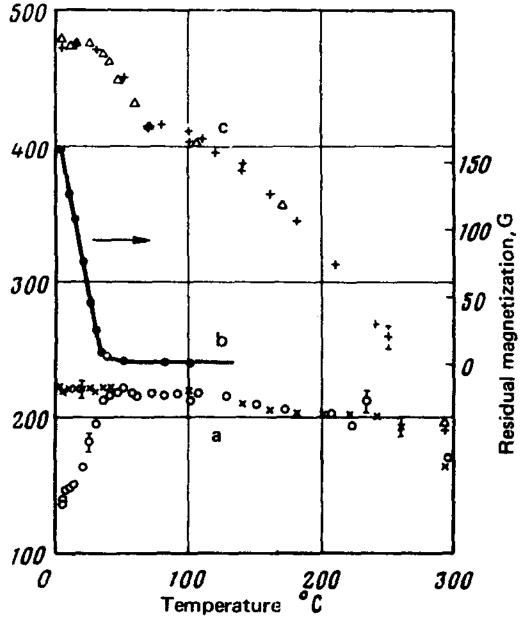

FIG. 1. Temperature dependences of: a) magnetization of a disordered $Ni_{75}Mn_{18}Fe_7$ alloy due to heating of the sample from 3.5 K in a field $H = 300$ Oe after cooling it to 3.5 K in a field $H = 0$ (o) and $H = 300$ Oe (x); b) residual magnetization I_R of the sample, which was cooled to 3.5 K in a field $H = 2000$ Oe after heating it in $H = 0$; c) magnetization of the sample in a field $H = 200$ Oe as a result of heating it from 3.5 K after cooling it in a field $H = 0$ (Δ) and $H = 2000$ Oe (+).

the relaxation of spin waves with $K \approx 0$ by using the ferromagnetic-resonance (FMR) method.

We investigated a disordered alloy with the composition: 75 at.% Ni, 18 at.% Mn, and 7 at.% Fe. Single-crystal parallelepipeds with sides of 0.1–0.2 mm and a length of ~4 mm were prepared for the FMR measurements. The long axis of the parallelepiped coincided with the <111> direction within an accuracy of 1–2°. The sample was thoroughly polished by using different methods. The resonance signal was removed from the middle portion of the sample to exclude the influence of inhomogeneity of the demagnetizing field at the sample's ends on the line width. The experiment was performed at a 9.8-GHz frequency. The external magnetic field was applied along the long side of the sample. The FMR line width ΔH was measured as the distance between the extrema of the derivative of the absorption with an accuracy of 8–10%. The magnetization I was investigated using a vibration magnetometer with an accuracy of at least 3%. The sample for the magnetization measurement was a disk with a diameter of 10 mm and a thickness of 1.5 mm. The resistivity ρ was determined by a potentiometric method. The values ΔH, I, and ρ were measured in the temperature range of 3.5 to 293 K, and the temperature of the experiment was maintained constant at each point with an accuracy of at least 0.5 K. ΔH and I were measured by heating the sample after cooling it to 3.5 K.

The temperature dependences of magnetization $I(T)$ are shown in Fig. 1(a)–1(c). The $I(T)$ dependences have a typical shape for alloys that undergo a double magnetic transition—at T_c and at T_0.[1] As we see in Fig. 1(a) and 1(b), the transition to the SGT state occurs at $T_0 \approx 50$ K. The Curie point of the $Ni_{75}Mn_{18}Fe_7$ alloy, according to Ref. 5, is $T_c \approx 350$ K.

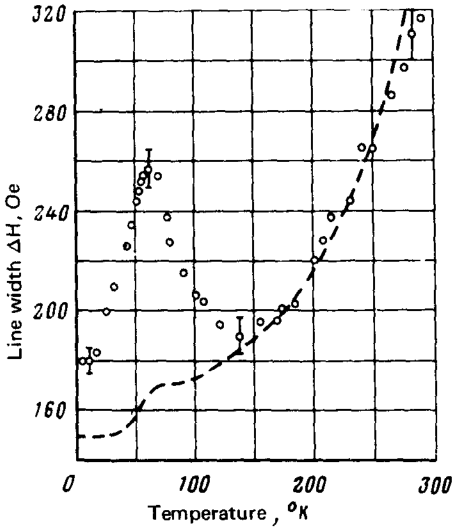

FIG. 2. Temperature dependence of the FMR line width $\Delta H\,(T)$ of a disordered $Ni_{75}Mn_{18}Fe_7$ alloy. o, Experimental points; ---, theoretical curve from the model.[7]

It is known that as the temperature drops below the Curie point the FMR line width in ferromagnetic alloys decreases because of an increase in the magnetization[7] and a decrease of the contribution to ΔH of the temperature fluctuations of the magnetization[4] ; ΔH remains almost constant as a result of further cooling to lower temperatures.[5] A comparison of the known temperature behavior $\Delta H\,(T)$ of ferromagnetic alloys with $\Delta H\,(T)$ of the $Ni_{75}Mn_{18}Fe_7$ alloy (Fig. 2) shows that the line width in this alloy behaves anomalously, i.e., it has a sharply defined maximum at $T_0 \approx 60$ K. We note that the resonance FMR field in the examined alloy varied within the limits 1500–2300 Oe in the investigated temperature range. We can see from a comparison of the temperature behavior of magnetization [Fig. 1(a)-1(c)] and the line width (Fig. 2) that the ΔH anomaly occurs at the temperatures of the transition of the alloy to the SGT state. Thus, we can see from our data that a relaxation of the long-wave magnons is pronounced near the transition to the spin-glass-type state; this additional contribution to ΔH amounts to almost 50%.

It is known[6] that the experimental line width ΔH consists of the broadening due to the skin effect ΔH_{skin} and the relaxation broadening ΔH_λ, which is phenomenologically described by the Landau-Lifshitz relaxation frequency λ; $\Delta H_{\text{skin}} \sim (A\sigma\omega)^{1/2}$ and $\Delta H_\lambda \sim \lambda\omega\gamma^{-2} I_0^{-1}$, where I_0 is the saturation magnetization, ω is the resonance frequency, and γ is the gyromagnetic ratio. Using the resonance-field data for the alloy in question, we determined $\gamma = 1.84 \times 10^7\ \text{sec}^{-1} \cdot \text{Oe}^{-1}$. The exchange parameter A was assumed to be $A = 0.55 \times 10^{-6}$ erg/cm. A permalloy with T_c and I_0 close to those of the alloy in question has such value of A. The alloy conductivity at $T = 4.2$ K was $\sigma\,(4.2) = 1.6 \times 10^6\ \text{ohm}^{-1} \cdot \text{m}^{-1}$ and it decreased monotonically to a value $\sigma\,(293) = 1.33 \times 10^6\ \text{ohm}^{-1} \cdot \text{m}^{-1}$ with an increase in temperature. The contribution to ΔH from ΔH_{skin} is $\leqslant 7\%$, and the observed line width is described by the relaxation broadening ΔH_λ within the accuracy limits of the experiment.

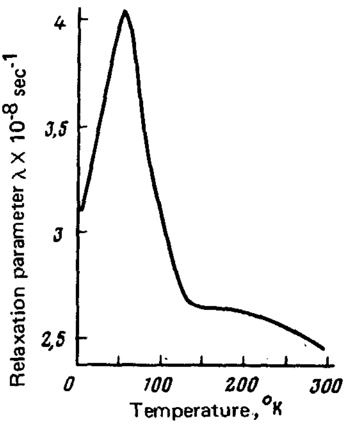

FIG. 3. Temperature dependence of the Landau-Lifshitz relaxation frequency $\lambda(T)$ of a disordered $Ni_{75}Mn_{18}Fe_7$ alloy.

The calculated relaxation frequency λ is shown in Fig. 3. The $\lambda(T)$ dependence for 130 K $< T <$ 293 K behaves the same as in ferromagnetic alloys, i.e., it slightly increases to a certain value as the temperature is lowered and then remains constant with a further decrease in the temperature.[5] however, $\lambda(T)$ behaves anomalously in the alloy in question—a maximum appears at $T_0 \approx 60$ K.

A relaxation mechanism, which quantitatively and qualitatively describes the observed FMR line width in ferromagnetic metallic alloys,[8] was recently proposed.[7] According to this model, the line width is caused by incoherent scattering of magnons and conduction electrons. The dashed curve in Fig. 2 represents the $\Delta H(T)$ dependence in the model,[7] which was calculated on the assumption that the $\Delta H(T)$ dependence is determined by the temperature dependence of magnetization. It can be seen that at $T >$ 130–140 K the relaxation model[7] correctly predicts the temperature dependence of the FMR line width in the disordered $Ni_{75}Mn_{18}Fe_7$ alloy; however, the damping mechanism[7] does not describe the observed temperature dependence $\Delta H(T)$ in the temperature region of the transition of the alloy to the SGT state. Apparently, there are additional relaxation mechanisms of magnons with $K \approx 0$, which are related to the transition of an alloy to the spin-glass-type state. An increase of ΔH at the SGT transition temperatures can be qualitatively explained: a) by the existence of different types of spin diffusion near T_0 (Ref. 9 and 10) in noncollinear, disordered, ferromagnetic materials and also in "pure" spin glasses and b) by the interaction of the spins of an infinite cluster with a sub-system of finite, magnetic clusters that undergo a transition at T_0 to the cluster-glass state; the observed $\Delta H(T)$ dependence in the investigated alloy is analogous to that in Au-Fe alloys.[11]

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