Instability of the perpendicular magnetization in multilayer Co/Pd films

S. A. Gusev, Yu. N. Nozdrin, D. B. Rosenshtein, A. A. Fraerman, M. G. Teitelman, and M. G. Shirokov

Institute of Applied Physics, Russian Academy of Sciences, 603600 Nizhniĭ Novgorod, Russia[1)]

(Submitted 14 May 1993)
Pis'ma Zh. Eksp. Teor. Fiz. **58**, No. 1, 35–38 (10 July 1993)

The temperature dependence of the perpendicular magnetization has been studied in multilayer Co/Pd films through measurements of the anomalous Hall effect. As the temperature is raised, the perpendicular magnetic moment becomes unstable in a zero field. This effect indicates the possibility of an orientational transition at a temperature between 40 and 400 K, depending on the properties of the films.

An orientational transition in ultrathin films—with a thickness of a few monolayers—has recently been observed experimentally and described theoretically.[1–4] A change in the sign of the perpendicular magnetic anisotropy in these films stems from pronounced 2D fluctuations of the magnetization.[3,4] In this letter we are reporting the experimental observation of an instability of the perpendicular remanent magnetization as the temperature is raised in multilayer films of ultrathin Co and Pd layers. This observation indicates that an orientational transition may occur in a multilayer system.

Multilayer Co/Pd films were grown by magnetron sputtering on mica and silicon substrates with Co thicknesses from 0.5 to 2 nm and Pd thicknesses from 0.5 to 3 nm. The total thickness of a structure was 20 nm. The thicknesses in the layers in the multilayer structure were monitored by small-angle x-ray scattering ($\lambda_{\mathrm{CuK}\alpha}=1.54$ Å; Fig. 1) and on the basis of the deposition time. The microstructure of the films was studied by transmission electron microscopy. The multilayer film consisted of a fine-grain polycrystalline material with crystallite sizes ~ 30 nm and a weakly expressed (111) texture (see the inset in Fig. 1).

The Hall resistance in a magnetic field perpendicular to the film was measured over the temperature range from 4 to 400 K. This resistance was found to vary between -10 kG and 10 kG. The Kerr effect was measured at room temperature through reflection of light with a wavelength $\lambda=0.63$ μm. The data found on the magnetization from the measurements of the Hall resistance and the Kerr rotation angle were in agreement.

At low temperatures the magnetization curve is nearly rectangular (Fig. 2). The perpendicular magnetic moment, magnetized to saturation, does not change in value in a magnetic field until the latter reaches $-H_a$. As the temperature is raised, the field H_a decreases, and at T_r it vanishes. At temperatures $T>T_r$ the perpendicular magnetic moment is unstable in a zero field, as can be seen from the significant decrease in the remanent magnetization in comparison with the saturation magnetization. The

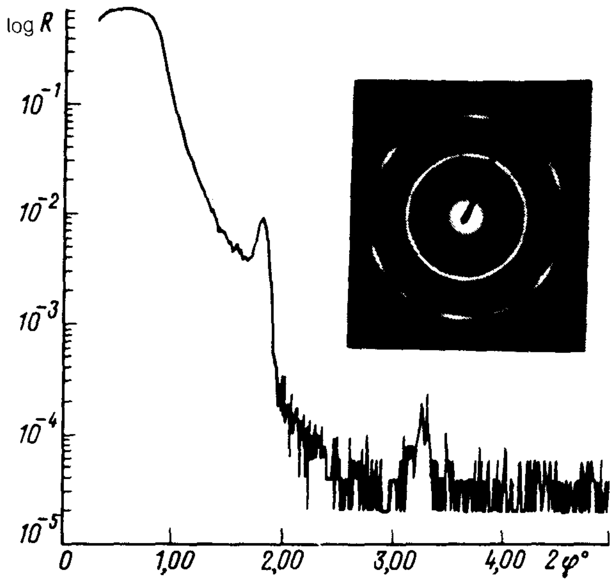

FIG. 1.

value of T_r depends on the thicknesses of the Co and Pd films in the multilayer structure. It follows from our experimental data that a reduction of the thickness of the Co films from 1.5 to 0.5 nm results in an increase in T_r from 40 to 350 K.

The temperature at which the instability arises, T_r, is well below the Curie temperature T_c. The observed effect is reversible, and the magnetization curves can be reproduced as the film temperature is varied over the range from 4 to 400 K.

Figure 3 shows the temperature dependence of the instability field for the magnetization H_a and that of the reduced Hall resistance in a saturating field (the data on the Hall resistance are given in different scales for samples 1–3). The film thicknesses are $h_{Co}=0.7$ and $h_{Pd}=2$ nm (sample *1*), $h_{Co}=0.5$ and $h_{Pd}=1.5$ nm (sample *2*), and

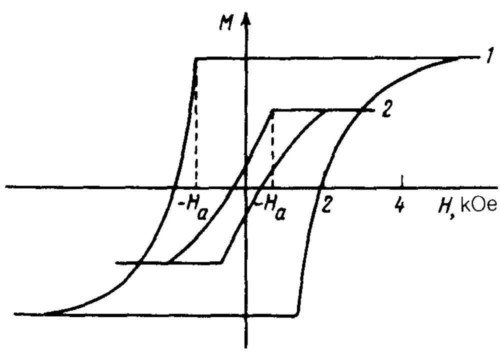

FIG. 2. Magnetization at various temperatures. *1*—$T=4$ K, $T<T_r$; *2*—$T=60$ K, $T>T_r$.

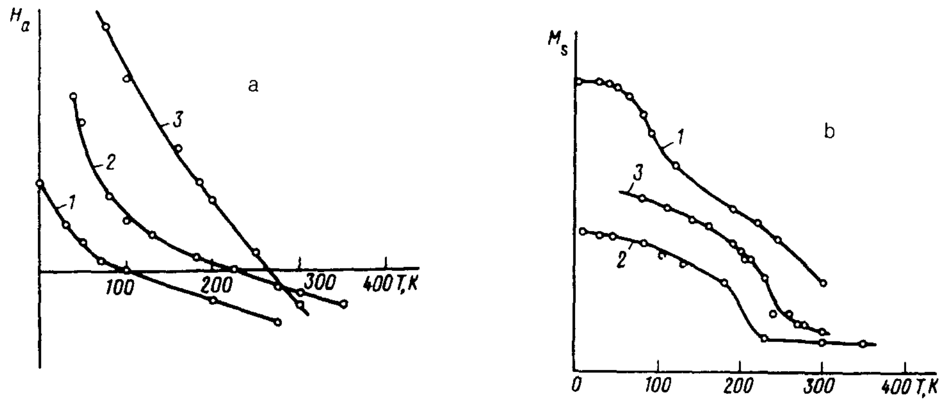

FIG. 3. Temperature dependence of two properties for samples *1–3*. a—$H_a(T)$; b—$M_s(T)$.

$h_{Co}=0.4$ and $h_{Pd}=1.4$ nm (sample *3*). Within the temperature dependence of the Hall constant, the temperature dependence of the Hall resistance determines the temperature dependence of the saturation magnetization.

The field H_a changes sign at $T=T_r$. This particular temperature depends on the properties of the sample (Fig. 3a). Significantly, the temperature dependence of the magnetization changes substantially at $T>T_r$ (Fig. 3b). These features can be explained in a natural way by assuming that the sign of the effective anisotropy parameter changes at T_r, and the temperature dependence $H_a(T)$ reflects the temperature dependence of the perpendicular-anisotropy parameter. Being geometrically 3D systems, the multilayer Co/Pd films may exhibit some quasi-2D properties, since the exchange coupling between Co layers is considerably weaker than the exchange with a single Co layer. The long-range order in a system of this sort is determined by the anisotropy energy and the magnetic dipole interaction.[5] The magnitude and nature of these interactions depend strongly on the thicknesses of the films in the multilayer structure.[6–8] At low temperatures the field H_a has a larger value for samples with thinner Co layers (Fig. 3a). This result agrees with the idea that the surface contribution to the anisotropy is important.[8] In quasi-2D systems, the magnetic dipole interaction can lead to a change in the sign of the effective anisotropy as the temperature is raised,[3,4] and the temperature dependence of the magnetization correlates with the temperature dependence of the anisotropy. It is totally unlike the linear dependence characteristic of 2D spin systems which have an anisotropy but which do not have dipole coupling.[3]

These experimental results suggest that an orientational phase transition may occur in multilayer Co/Pd films.

[1)]e-mail: teite ± appl.nnov.su.

[1]J. J. Krebs, B. T. Jonker, and G. A. Prinz, J. Appl. Phys. **63**, 3467 (1988).

[2]D. P. Pappas, K.-P. Kämper, and H. Hopster, Phys. Rev. Lett. **64**, 3179 (1990).
[3]M. G. Tetel'man, Zh. Eksp. Teor. Fiz. **98**, 1003 (1990) [Sov. Phys. JETP **71**, 558 (1990)].
[4]D. Pescia and V. L. Pokrovsky, Phys. Rev. Lett. **65**, 2599 (1990).
[5]L. D. Landau and E. M. Lifshitz, *Statistical Physics* (Pergamon, New York, 1980).
[6]P. J. H. Bloemen, C. H. W. Swüste, G. J. M. Poodt *et al.*, J. Appl. Phys. **67**, 4470 (1990).
[7]J. Q. Xiao, A. Gavrin, Gang Xiao *et al.*, J. Appl. Phys. **67**, 5388 (1990).
[8]C. M. Falco, Phys. Rev. Lett. **67**, 1910 (1991).

Translated by D. Parsons