1. INTRODUCTION

Interest in multilayer magnetic structures that contain magnetic layers and an intermediate nonmagnetic layer is caused by their practical use in spintronic devices. Controlling layers in such devices are the magnetic layers that are made of magnetic materials with different coercive forces. Physical properties of such structures in many respects depend on the state of high-coercive layer. Up to now, magnetic properties of multilayer films in the region of nanothicknesses and, specifically, the effect of high-coercive layer on them are poorly understood. This problem seems to be topical from the fundamental and practical viewpoints, and its solution will provide prediction and formation of magnetic multilayer systems with specified properties.

In this paper, we report on the investigation of an unusual magnetic aftereffect in trilayer magnetic films with a thin high-coercive layer.

2. SAMPLE PREPARATION AND EXPERIMENTAL TECHNIQUE

The samples under study were the trilayer films prepared by chemical deposition. The first magnetic isotropic high-coercive layer is made of the Co–P compound in the polycrystalline state [1] deposited on a glass substrate from the solution.

The intermediate layer was an amorphous nonmagnetic alloy of Ni and P, which was achieved by the corresponding phosphorus content [3].

We studied the samples of two types. In the first-type samples, we fixed the thicknesses of the low-coercive $d_2$ and nonmagnetic $d_3$ layers, while the thickness of a high-coercive layer $d_1$ was varied in the range of 1–25 nm. In the second-type samples, we fixed the thicknesses of the high-coercive and intermediate layers, while the thickness of the low-coercive layer was varied in the range of 0.5–120 nm. Preparation of samples without the intermediate layer with an abrupt transition boundary between the layers is complicated in this technology. This is caused by that at the initial stage of deposition, because of the epitaxial character of the film growth, the first layers will copy the structure of the sublayer.

The chemical composition of the films and their thickness were monitored using the photocalorimetric and X-ray spectral analyses.

The hysteresis loops were measured using the meridional and polar Kerr effects with the frequency of the change of the magnetic field of 0.01 Hz and by the induction method with the frequency of 50 Hz. The dynamic changes of hysteresis loops were recorded on the oscilloscope screen with a WEB camera and written into a videofile. The structural investigations of the film surface were performed using an atomic force microscope.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The films were preliminarily saturated in a constant magnetic field exceeding the coercive force of the
high-coercive layer and directed along the easy magnetization axis of the low-coercive layer. After this magnetization, hysteresis loops of the low-coercive layer shifted by quantity $h_d$ with respect to the zero value of the external magnetic field in the direction opposite to the magnetization direction of the high-coercive layer (in the positive direction). Upon the magnetization reversal of the film, the value of $h_d$ decreased with time, and after a lapse of time, the hysteresis loops acquired a shape inherent in the single-layer film. These changes in $h_d$ depend on the amplitude of the magnetization reversal field $h$: with an increase in $h_d$, the rate of change in $h_d$ increases. If the amplitude of the magnetic field is selected so that it would somewhat exceed the coercive force of the low-coercive layer, we can establish that the variation of $h_d$ with time depends on the thickness of the hard-coercive layer. The time of change in $h_d$ with increasing thickness of the hard magnetic layer increases as shown in Fig. 1.

Figure 2 shows the plot of the dependence of the bias field on the thickness of the hard magnetic layer at the magnetization reversal frequencies 0.01 Hz (measured using the meridional Kerr effect) and 50 Hz (measured by the induction method). The largest differences in the values of $h_d$ determined by these methods are observed when the thicknesses of the hard magnetic layer are less than 10 nm. No differences in the values of $h_d$ measured by these methods are observed in the range of larger thicknesses.

It was established previously [4] that the variation in the thickness of the high-coercive layer exerts a substantial effect on the value of the coercive force $H_c$ of the low-coercive layer. As the thickness increases to ~10 nm, $H_c$ decreases, reaches the minimum value, and increases with a further increase in $d_1$. These changes in the coercive force especially clearly manifest themselves when increasing frequency of the magnetic field, which leads to the largest differences in the values of the coercive force measured using the magneto-optical and induction methods when the thickness of the hard magnetic layer is less than 10 nm (Fig. 3).

According to Néel [5], the magnetic aftereffect during the quasi-static magnetization reversal can be caused by two physical mechanisms, namely, by the diffusion of the particles and thermal spin fluctuations. Despite the apparent similarity, these phenomena have fundamental distinctions. During the diffusion aftereffect, instant directions of the magnetic moment are stabilized by the diffusion of particles, and as the rate of varying the magnetic field decreases, the coercive force should increase. With the fluctuation mechanism, as the rate of varying the magnetic field decreases, the coercive force decreases since the spin fluctuations induce an additional internal magnetic field.