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Study of domain wall pinning in magnetized cobalt composite based on epoxy matrix by NMR and RF magnetometry

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The processes of domain wall pinning and coercivity in cobalt nanowires oriented by external magnetic field in the epoxy matrix were studied during their magnetization reversal. The methods used were NMR (the spin echo method involving the additional magnetic video pulse) and RF magnetometry. Information on the domain wall pinning force in dependence on the magnetic field direction relative to the cobalt composite magnetization and its coercive force was obtained.

Keywords: cobalt, nanowires, NMR, magnetometry, pinning, coercivity.

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Nuclear magnetic resonance (NMR) in magnetically ordered materials was observed for the first time by Gossard and Portis in ferromagnetic cobalt [1]. The main difference between magnetic and non-magnetic materials is the presence of a strong local magnetic field and significant enhancement of the resonant radio frequency (RF) field acting on the nuclei, especially in the domain walls (DWs) [2–4].

Since DW is easily displaceable under the exposure to an additional magnetic video pulse (MVP), the latter may be conveniently used in studying the DW pinning and mobility [5,6].

When MVP acts in the interval between the RF pulses, the double-pulse echo (DPE) signal decreases approximately in proportion to the product of the MVP amplitude by its duration [7–10]. In this case, the echo signal attenuation occurs due to the loss of phase coherence of the precessing isochromats caused by an inhomogeneous shift in the NMR frequency on the nuclei when DW gets displaced due to anisotropy of the DW hyperfine field. Pinning force H_0 was measured in the samples to be studied under the condition when DPE signals were exposed to an additional MVP. As the force value, we accepted the MVP amplitude from which suppression of the DPE signal began due to the MVP-induced displacement of DW.

A preliminary NMR study of the DW pinning force in cobalt composites estimated its value as about 100 Oe and higher [11]. It should be expected that external magnetic field H_e necessary for magnetization reversal of the oriented composite is close to the DW pinning force in it.

To obtain external magnetic field H_e ranging from 0 to 200 Oe, Helmholtz coils were used.

To characterize the magnetic properties of the obtained samples, the RF magnetometry method was used in addition to the NMR method [12].

The magnetometer comprises a standard-circuit *LC* resonant generator involving field-effect transistors. The essence of the method is to control the sampleś magnetic susceptibility by measuring variations in resonant frequency $\Delta f(H_e)$ of the *LC*-generator with the sample in its resonant circuit under the influence of external magnetic field H_e.

The goal of this study was to compare NMR and magnetometry data in studying the indicated samples.

NMR measurements were performed using a phase-incoherent spin echo spectrometer [11] in the frequency

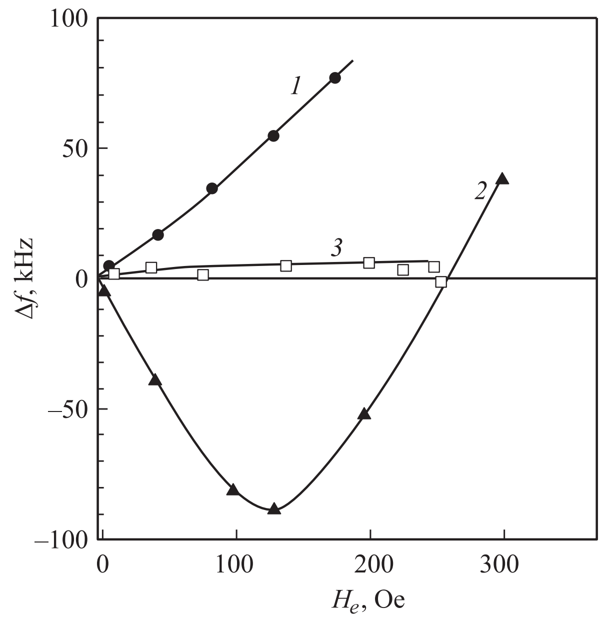

Figure 1. Resonant frequency of the *LC* generator with a cobalt-composite sample in its resonant circuit versus magnetic field H_e. *1* — along the sample magnetization, *2* — in the opposite direction, *3* — perpendicular to magnetization.

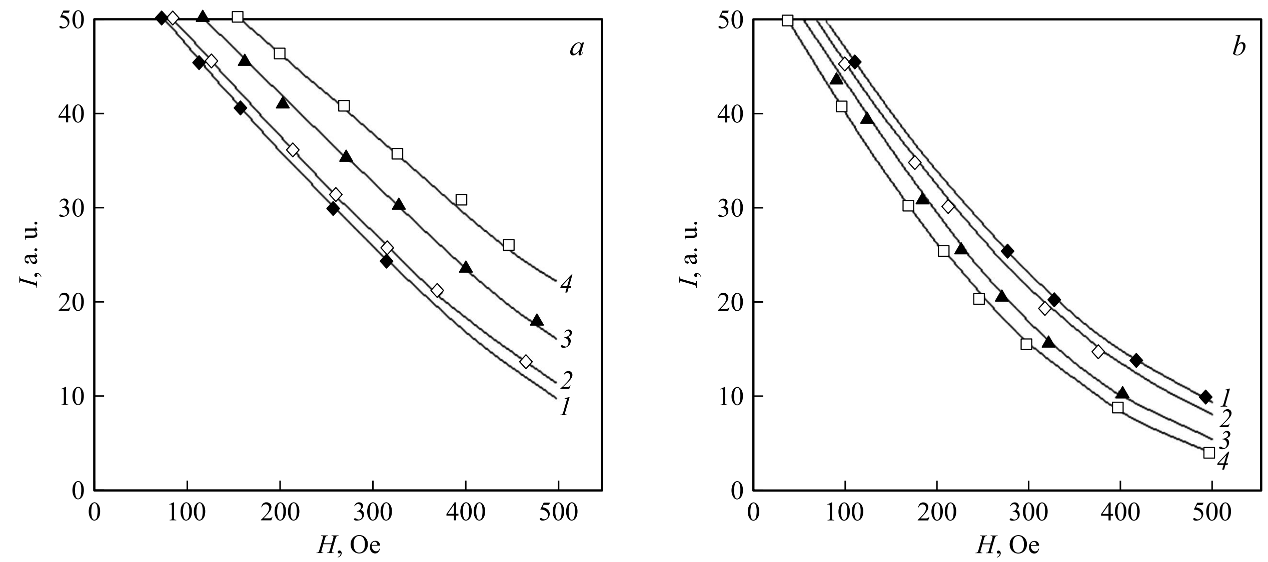

Figure 2. DPE signal intensity (I) versus the MVP amplitude (H) for the external magnetic field oriented along the sample magnetization (a) and opposite to magnetization (b). H_e, Oe: *1* — 0, *2* — 80, *3* — 120, *4* — 170. MVP duration is $\tau_m = 1\,\mu$s.

range of 200−400 MHz at 293 K at the frequency of 213 MHz corresponding to the maximum intensity of the sample NMR signal.

MVP was formed by a gated adjustable-amplitude current stabilizer with an additional coil allowing creation of magnetic field pulses about 500 Oe in amplitude on a cylindrical sample 10 mm in length and 6 mm in diameter with the 50% weight concentration of cobalt in the composite.

To prepare the samples, we used cobalt nanowire (PlasmaChem GmbH) 200−300 nm in diameter and up to 200 μm in length (note that diameter of the nanowire supplied by the manufacturer was 200−300 nm, i e. its size corresponds, more likely, to microwires).

Epoxy capsules containing cobalt nanowires were fabricated. For this purpose, nanowires were placed in a polyethylene tube containing epoxy resin and then subjected to orientation in external magnetic field of 500 Oe for 24 hours.

Fig. 1 illustrates variations in the *LC* oscillator resonant frequency $\Delta f(H_e)$ with under the action of external magnetic field H_e (initial resonant frequency $f_0 = 10$ MHz) directed along or across the sample magnetization.

The dependence exhibits a hysteresis similar to that in the dependence given in [13]..

The $\Delta f(H_e)$ dependence minimum observed at the external magnetic field of ~ 130 Oe corresponds to the maximum of susceptibility χ_{dw} associated with the DW displacement. As per [13], this H_e value also provides an estimate of the sample coercive force H_c.

Fig. 2 demonstrates the echo signal amplitude dependences on the MVP field amplitude, which were used to examine variations in DW pinning force H_0 at the selected external field directions.

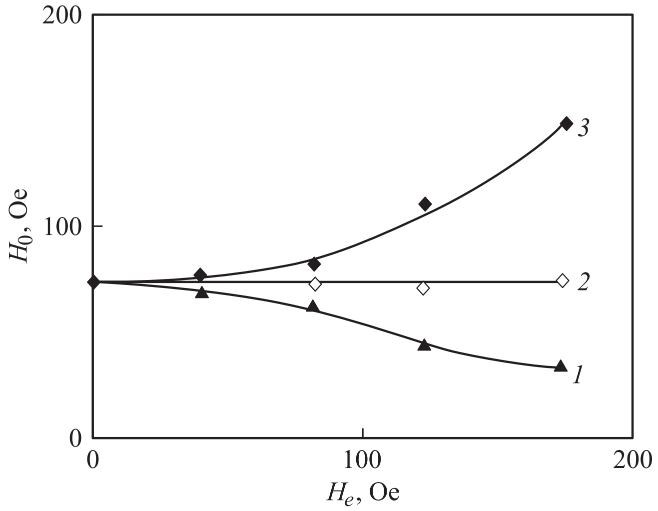

Figure 3. Pinning force H_0 versus external field H_e for three external field directions: opposite to (*1*), across (*2*) and along (*3*) the sample magnetization. $\tau_m = 1\,\mu$s.

Based on the results obtained, it is possible to construct pinning force H_0 dependences for the three cases considered (Fig. 3).

Thus, in case H_e is directed along the nanowire magnetization, H_0 increases, while, when the magnetic field direction is opposite to the sample magnetization, H_0 decreases and reaches the minimum at $H_e \approx H_c$.

However, if the nanowire magnetization is directed across the magnetic field, the DW pinning force remains almost unchanged in the considered range of H_e.

DW pinning force H_0 is close to the value of the sample coercive force H_c at the MVP duration $\sim \tau_m = 1\,\mu$s. However, this closeness is ambiguous since pinning force H_0

varies with the MVP duration [10]. This is because H_0 is being determined based on the condition of approximate constancy of the MVP area threshold $A = H_0\tau_m$, i.e. it is inversely proportional to MVP duration τ_m.

Note in conclusion that we have performed the NMR and magnetometric studies of the domain wall pinning force in the epoxy-matrix-based cobalt composites, as well as of their coercivity. The studies have demonstrated an increase in the domain wall pinning force with the external magnetic field increasing along the cobalt composite magnetization and its decrease with the field increasing in the direction opposite to magnetization; in addition, a weak pinning force dependence on external field directed perpendicular to magnetization was revealed.

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Conflict of interests

The authors declare that they have no conflict of interests.

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