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DC magnetization processes in bistable glass-coated ferromagnetic microwires

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ABSTRACT

Interaction of a single magnetic domain wall with an inhomogeneous magnetic field and distribution of local nucleation fields along glass-coated $Fe_{77.5-x}Ni_xB_{15}Si_{7.5}$ (x=0, 27.9, 34.9) microwires were experimentally studied. It was shown that the wall separating two axial domains and moving along the wire can be stopped by an inhomogeneous magnetic field. The wall remains stable and trapped in a local potential minimum after external fields are switched off. Wall coercivity increases with Ni content. For all samples the minimum of critical field for axial magnetization reversal was observed near the end of the wire. For samples with non-zero Ni content a distribution of nucleation fields lower than 950 A/m was observed in regions far enough from the wire ends. In Ni-free samples the nucleation fields were higher than 950 A/m.

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1. Introduction

Amorphous ferromagnetic wires with circular cross section are novel materials with unique magnetic properties. They are prepared in two basic forms. Wires with diameter of about 100 μm are prepared using the so-called in-rotating-water quenching technique. Glass-coated magnetic microwires with the diameter from a few micrometers to a few tens of micrometers are prepared by the Taylor–Ulitovski method [1,2]. In both procedures rapid quenching results in materials with complex distribution of mechanical stresses [1,3]. Magnetoelastic anisotropy therefore becomes the dominant anisotropy in high magnetostrictive wires and together with shape anisotropy determines their magnetic properties. Magnetic reversal by a large Barkhausen jump is typical for wires with high positive magnetostriction. Stray fields at the ends of the wire cause a closure domain to form. At a certain critical field the reversed domain at the end of the wire starts to increase its volume by propagation of a single domain wall. The dynamics of such a single domain wall in glass-coated magnetic microwires have been intensively studied during the last few years [4,5,6]. Recently studies of distribution of local nucleation fields of reversed domains along microwires have been published [7,8]. Nucleation of such domains can accelerate magnetization switching in magnetically bistable microwires [9].

In this paper we present a new experiment in which a single domain wall moving along a wire can be stopped by an inhomogeneous magnetic field. It is demonstrated that this wall remains stable at a given position after the external magnetic fields are switched off. Its position can be easily manipulated by applying an axial magnetic field, and information on the coercivity of this single wall can be obtained.

Typically magnetization reversal starts at the wire end. This prevents any information being obtained about the magnitude of local nucleation fields within the middle parts of a microwire using hysteresis loop measurement. Measurements of local nucleation fields in the middle parts of a microwire were presented in [7]. We slightly modified the experimental procedure proposed in that work, and measured the distribution of critical fields (depinning or nucleation) close to the end and also in the middle parts of the microwire.

2. Experimental

The system of magnetizing coils used in the experiments is schematically depicted in Fig. 1. It consists of a long solenoid and two identical thin coils in the Helmholtz geometry (coils are separated by a distance equal to the coil radius). A sample holder with L=1.5 cm long pick-up coil is set at a fixed position in the center of the solenoid, and the position of the Helmholtz coils along the solenoid can be changed.

The magnetic fields generated by the Helmholtz coils were calibrated, and the results are shown in Fig. 2a. The field as a function of the position on the z axis can be calculated using the

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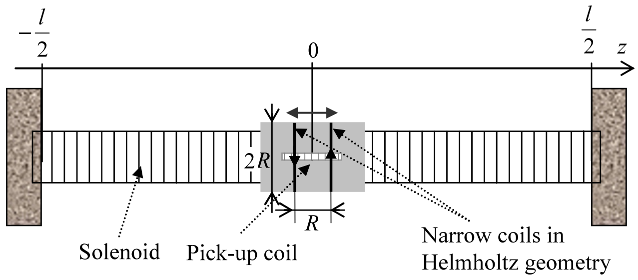

Fig. 1. System of magnetizing coils consisting of a solenoid and two narrow coils in the Helmholtz geometry. Length of the pick-up coil is $L=1.5$ cm, $l=15$ cm and $R=6$ mm.

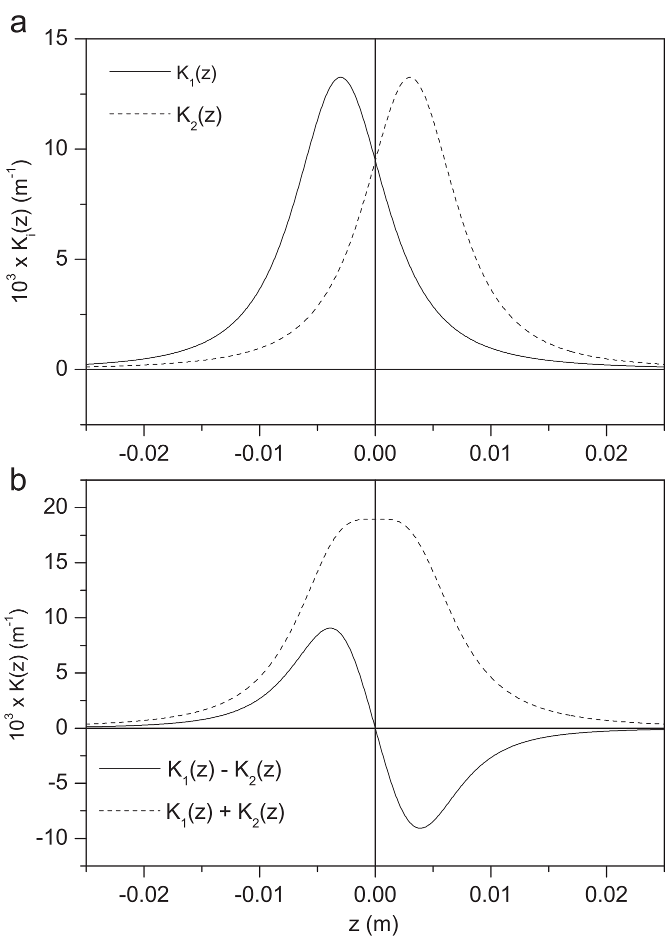

Fig. 2. Magnetic field distribution generated by the Helmholtz coils as a function of position for (a) single and (b) parallel and anti-parallel combinations of coils.

formula $H_i(z)=K_i(z)I$, where I is the current in the winding of a given coil. Field distribution along the z axis is shown in Fig. 2b for parallel and anti-parallel currents in the Helmholtz coils.

Magnetic fields generated by solenoid H and by the Helmholtz coils H_H were controlled by computer. The pick-up coil was connected to the input of an integrating amplifier. Magnetic flux changes were measured by the induction method. More details can be found in [10].

The measurements were carried out on glass-coated $Fe_{77.5-x}Ni_xB_{15}Si_{7.5}$ ($x=0$, 27.9, 34.9) microwires prepared by the Taylor–Ulitovski method. Diameter of the metallic core was about 15 μm and the thickness of glass coating was about 18 μm. Wires of this composition are known to exhibit bistable behavior [5]. Magnetization reversal starts at the wire ends by depinning of a single wall and proceeds by its rapid movement along the wire. In our experiments a sample of length of 12.5 cm was placed in the solenoid in such a way that its left and right ends were at positions $z_{left}=-3$ cm and $z_{righ}=9.5$ cm, respectively. The right end of the wire was outside the solenoid, so that depinning of the wall from this end was less probable than from the left one.

3. Results and discussion

3.1. Interaction of the domain wall with inhomogeneous magnetic field

First, we started with an experiment in which a single domain wall interacted with an inhomogeneous field H_H created by the Helmholtz coils. The centers of the Helmholtz coils in anti-parallel combination and the pick-up coil approximately coincided during this experiment. Variations of the field in the vicinity of the pick-up coil are shown in Fig. 3. The dependences are plotted for $H=0$ and for $H=\pm H_k$, where H_k is the critical field at which the wall starts propagating from the left end of the wire. Depending on the sign of magnetization in adjacent domains the field H_H creates a potential barrier (local maximum) or a potential well (local minimum) for the DW, which separates these domains (point 3). As a consequence magnetization reversal in the field H, by the displacement of a single DW from the left end of the wire, depends on the sign of saturating field H. In other words hysteresis loops measured at time-constant inhomogeneous field H_H can be expected to be asymmetric. For $Fe_{77.5}B_{15}Si_{7.5}$ wire hysteresis loops of this type are shown in Fig. 4. It is important to point out that these loops were not measured during continuous change of driving field H. Prior to the measurement of each point the wire was repeatedly magnetically saturated in the field H. Then this field was changed to

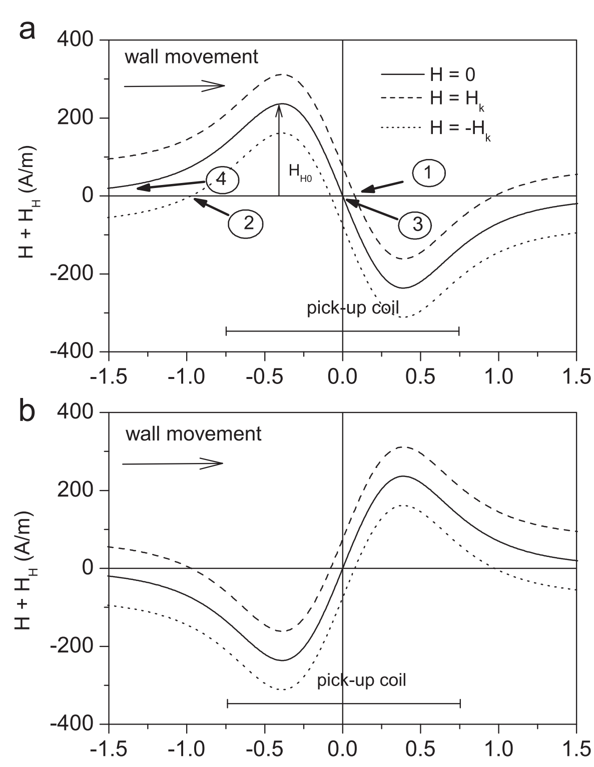

Fig. 3. Field distribution in the region around the pick-up coil for inhomogeneous field amplitudes $H_{H0}=\pm 235$ A/m. $H_k=90$ A/m is the magnitude of the field at which DW starts propagating from the left end of $Fe_{77.5}B_{15}Si_{7.5}$ microwire.

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