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Basic study of magnetic microwires for sensor applications: Variety of magnetic structures

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ABSTRACT

We examine magnetic glass-coated microwires used for magnetic sensors. Images of domain structures and magnetization reversal were obtained with magneto-optical Kerr microscopy. Of particular importance were temperature-induced transformations of surface magnetic structures. Different surface magnetic domains coexist, characterized by various domain periods, magnetization directions, and nobilities of domain walls.

1. Introduction

The temperature behavior of magnetic glass-coated microwires is receiving considerable attention with respect to sensor applications [1–6]. Here, we reveal a large variety of domain structures in the microwires. Temperature-induced transformations of the magnetic structures are a key process that determines the stable operation of wire-based sensors and detectors. In particular, we examine the heat-induced transformation of surface domain structures. Despite their importance in efforts to increase magnetic sensor efficiency, these transformations in microwires have not been studied systematically.

As illustrated in Figs. 1–3, there are three basic types of domain structures in microwires. The circular mono-domain structure (Fig. 1) has been observed in glass-coated microwires having a nominal composition of $Co_{67}Fe_{3.85}Ni_{1.45}B_{11.5}Si_{14.5}Mo_{1.7}$. The radius of the metallic nucleus is 11.2 μm, the thickness of the glass coating is 3 μm, and the ratio of the metallic nucleus diameter to the total microwire diameter ρ is 0.79. The domain structure was induced by the circular magnetic field H_{cir} produced by electric current flowing through the wire [7]. Generally, for the giant magneto-impedance effect, which is the basis of microwire sensors [6], circular and axial fields are combined. The application of only a circular field in a wire that has circular surface anisotropy mainly suppresses domain nucleation. It causes, in turn, the long-distance displacement of solitary domain walls (DWs). Circular multi-domain structures (Fig. 2) have been observed in the same microwire in the presence of only axial magnetic fields [8]. Formation and transformations of regular surface domain structures occur in the relatively short range of the axial field, and are accompanied by multiple DW displacements.

This effect reflects the correlation between the axially magnetized inner core and the circularly magnetized outer shell in a microwire that has circular surface anisotropy. Initially, the axial field induces domain nucleation in the inner core. The surface domains appear as a response to the inner domain nucleation. It was found that the “left” and “right” direction of the circular magnetization directly correlates with the “forward” and “back” magnetization direction in the inner domains.

The vortex-like structure (Fig. 3) has been observed in microwires with the nominal composition of $Fe_{5.71}Co_{64.04}B_{15.88}Si_{10.94}Cr_{3.40}Ni_{0.03}$. The radius of the metallic nucleus is 50 μm, the thickness of the glass coating is 20 μm, and $\rho = 0.7$. The vortex structure was induced by a magnetic field H_Σ that was a vector superposition of the axial and the circular magnetic fields. Generally, the H_Σ vector rotates in a cylindrical shape and follows a non-planar inclined trajectory. Successive increases in the circular field result in competition between different helical structures, as well as between domain nucleation and DW propagation. Co-existence of helical structures is realized in a specific multi-domain structure when the DW angle alternates along the wire. DWs that separate different helical states have different angles of inclination and a different velocity. When H_{cir} is high enough, the different helical structures are captured into a

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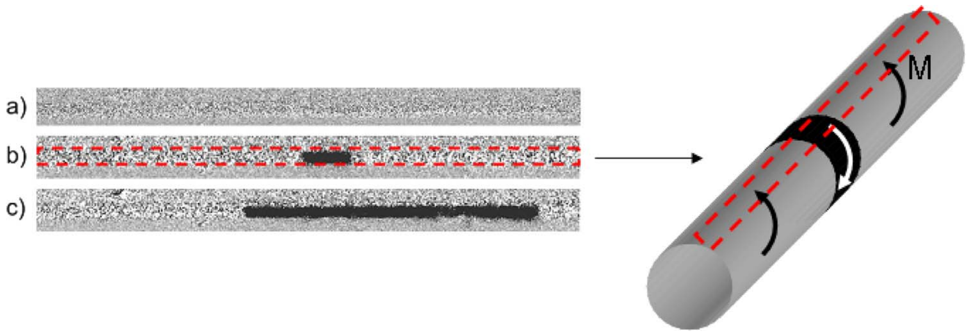

Fig. 1. Basic mono-domain surface structure. Image size is 270 × 22 μm^2. The dashed line shows the part of the cylindrical surface that was observed.

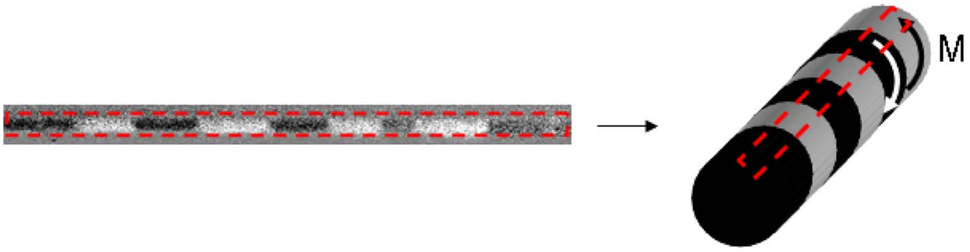

Fig. 2. Basic multi-domain surface structure. Image size is 170 × 50 μm^2. The dashed line shows the part of the cylindrical surface that was observed.

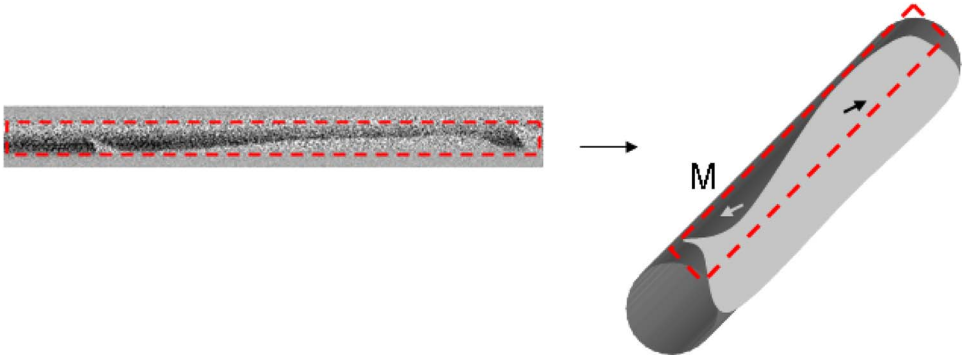

Fig. 3. Basic vortex-like surface domain structures. Image size is 720 × 150 μm^2. The dashed line shows the part of the cylindrical surface that was observed.

magnetization reversal, initiating the simultaneous coexistence of four magnetic structures in the form of a surface non-planar vortex.

Temperature changes must affect domain structures dramatically because of the complex structure of glass-coated microwires. Microwire magnetic structures have axially magnetized inner cores and circularly (or radially) magnetized outer shells. Additional contributions come from specific distributions of internal stresses inside the microwire and the effects of the glass coating. Here, we present the results of a magneto-optical study of surface domain structures and magnetization reversal performed in the 20–200 °C temperature range.

2. Experimental

We examined glass-coated amorphous microwires having the nominal composition of $Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$ (37.6-μm metallic nucleus radius, 7.7-μm glass thickness). Imaging of the surface magnetic domains on the microwires was performed with polarized optical microscopy, using the magneto-optical Kerr effect (MOKE) (Fig. 4) [9]. The magnetic contrast of the domain structures was visualized because of different magnetization components when polarized light reflects from the cylindrically shaped surface of the microwire. The thermally controlled MOKE microscope stage was varied over a 20–200 °C temperature range. The heating rate was 1°/1 min. Hysteresis loops were obtained by measurement of the averaged image contrast of the microwire surface as a function of the external axial magnetic field. The

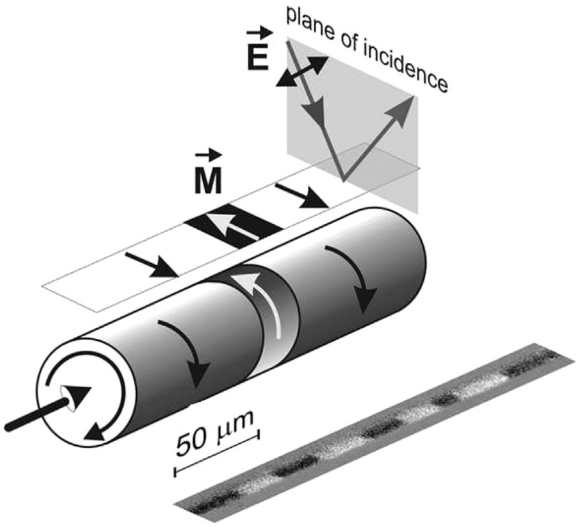

Fig. 4. Longitudinal MOKE images of cylindrically shaped microwires.