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Experimental demonstration of basic mechanisms of magnetization reversal in magnetic microwires

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ABSTRACT

We report on the magneto-optical study of surface magnetization reversal in glass covered Co-rich microwires. Four different mechanisms of magnetization reversal were found to exist, depending on external magnetic field configuration. An analysis of the results obtained was performed using the theoretical model which proposes the existence of four magnetization states with different chirality. This model was developed previously to describe current-induced switching in wires with variable inner core radius. The co-existence of stable and meta-stable helical magnetic states on the microwire surface is the basic reason for the variety of mechanisms observed for the magnetization reversal.

1. Introduction

The study of the magnetic properties of glass-covered amorphous microwires is a topic of growing technological interest related to their peculiar magnetic behaviour such as magnetic bistability and giant magnetoimpedance effect (GMI). The GMI effect provides opportunities for the use of magnetic wires in sensor elements. Optimization of amorphous wires for sensor applications requires investigation of their electric and magnetic properties. Because the GMI effect is mainly a surface effect, the surface magnetic domain structure of the microwires must be investigated for this optimization [1–4].

The magnetization reversal process mechanism in magnetic wires is the subject of much discussion in experimental and theoretical work where magnetization processes and domain wall (DW) motion have been studied [5–8]. We have noted the lack of information in this area during our extensive and systematic studies of the magnetic and magneto-optical properties of Co- and Fe-rich glass covered amorphous microwires. We have therefore studied a series of glass covered microwires of different compositions, metallic nucleus diameters (0.8–100 μm) and glass covering thickness (2–50 μm). The microwire of nominal composition $Fe_{5,71}Co_{64,04}B_{15,88}Si_{10,94}Cr_{3,40}Ni_{0,03}$ (metallic nucleus radius 50 μm, glass coating thickness 20 μm, ratio of metallic nucleus diameter to total microwire diameter $\rho = 0.7$) has a great variety of surface domain structures and was selected for the detailed study of the field induced modification of surface magnetic structure. The geometry and composition of the microwire were determined during the microwire fabrication process by the Taylor–Ulitovsky method [9].

We then investigated the surface magnetic properties of this microwire using the magneto-optical Kerr method to determine the basic mechanisms of the magnetization reversal process.

2. Experimental details

Magnetic domain imaging of the microwire surface was performed by optical polarizing microscopy in reflection mode using the longitudinal magneto-optical Kerr effect (MOKE) configuration [10]. Surface magnetic domains were observed because the different in-plane components of the surface magnetization transform to black–white contrast when polarized light reflects from the cylindrically shaped microwire surface. Therefore, images of the domain structures obtained by MOKE microscopy show differences of the in-plane magnetization components.

The microwire was illuminated using plane-polarized light provided by a stable xenon lamp and created by a polarizer. The magneto-optical Kerr effect causes a rotation of the polarization plane of light, which depends on the domain magnetization

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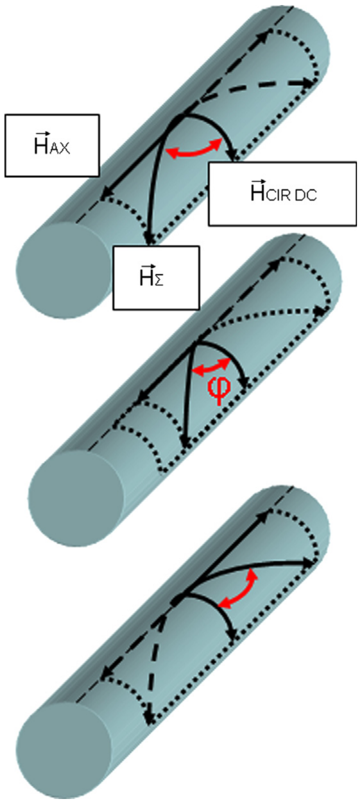

Fig. 1. Configuration of magnetic fields.

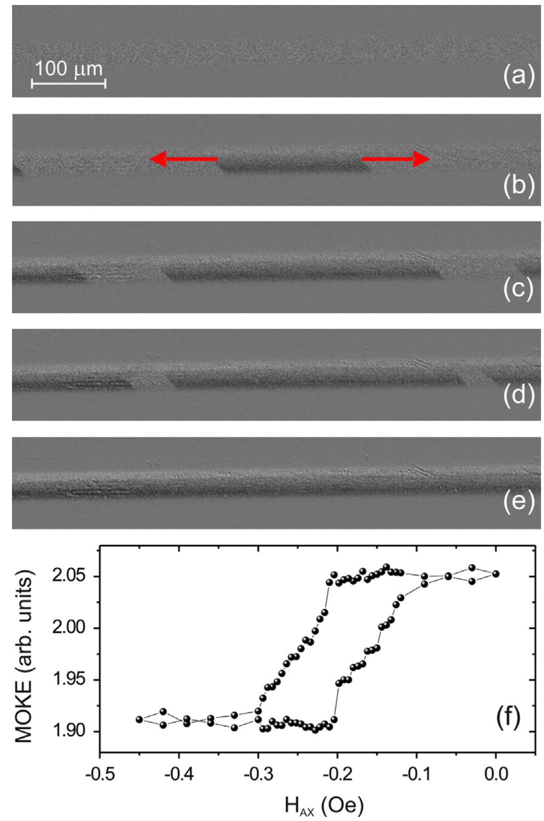

Fig. 2. Images of surface magnetic domain structure transformation for: $H_{CIRC\ DC}=0$ and: (a) $H_{AX}=-0.15$ Oe; (b) $H_{AX}=-0.22$ Oe; (c) $H_{AX}=-0.24$ Oe; (d) $H_{AX}=-0.27$ Oe; (e) $H_{AX}=-0.39$ Oe. The hysteresis loop (f) obtained from images of domain structures.

direction and can be transformed into a contrast using an analyzer. The MOKE contrast is rather weak, thus a high sensitivity and fast-frame rate CCD camera and image processing technique (including subtraction of the reference image) are required for contrast enhancement in real-time. A computer-controlled set-up enables the adjustment of the image acquisition time as well as the generation of external magnetic field. Simultaneously, surface hysteresis loops were measured as the grey scale intensity in pixels of CCD camera for different values of magnetic field.

In this study, we have focused on surface domain structure transformation. Experiments were performed using a magnetic field (H_Σ) which was the vector sum of alternating axial (H_{AX}) and DC circular magnetic ($H_{CIRC\ DC}$) fields. Vector H_Σ rotates in a cylindrical shape (Fig. 1) and follows the non-plane inclined trajectory. The shape of this line depends on the value of $H_{CIRC\ DC}$. To produce the circular magnetic field, an electric current flowing through the wire was used. A pair of Helmholtz coils provided an axial magnetic field.

3. Experimental results and discussion

First, the magnetization reversal was studied for $H_{CIRC\ DC}=0$. Images of the domain structures obtained for the magnetic field applied parallel to the wire axis are presented in Fig. 2. In this case, the light incidence plane is perpendicular to the wire axis. Thus, the observed magneto-optical contrast is proportional to the component of magnetization in the direction perpendicular to the wire axis (circular magnetization). Fig. 2(a)–(e) shows the successive domain structures obtained by increasing field H_{AX}. The magnetization loop obtained from the MOKE images is shown in Fig. 2(f). Fig. 2(a) corresponds to the mono-domain magnetic state (bright image, $H_{AX}=-0.15$ Oe). The opposite dark magnetic domain appears at the sample surface when the amplitude is -0.22 Oe. When the magnetic field sweep continues, the dark domains increase with a simultaneous decrease in bright domains (Fig. 2(b)–(d)). The last bright domains are seen for $H_{AX}=-0.27$ Oe. Results from this experiment agree well with previous results on the long distance rapid motion of solitary circular DWs [9].

It should be noted that the main difference between our results and previous results [9] is the inclined shape of the DWs. This case could be considered to be more general, taking into account that the DWs which divide the circular domains [9] is a special case of inclined DWs which separate the helical magnetic domains.

Next we discuss the experiments conducted in the presence of a DC circular magnetic field. An increase in circular magnetic field causes successive changes in the mechanism of magnetization reversal. Here we present three different types of this mechanism as a dependence on $H_{CIRC\ DC}$ amplitude.

Fig. 3 presents the transformation of the surface domain structure induced by the axial magnetic field for $H_{CIRC\ DC}=0.48$ Oe. In this case, we also start from the mono-domain configuration (Fig. 3(a)). In the initial stage, magnetization reversal occurs in the same way as in the previous case (see Fig. 2), domain nucleation is followed by DW motion across the sample (Fig. 3(b)), but the size of the nucleated domains is relatively smaller. However, in the next step, the mechanism of magnetization reversal changes. In this case, domain suppression is observed (Fig. 3(c)–(e)). The advantageous dark domain placed in the centre of the frame, disappears under the pressure of two DWs that have moved (marked by red arrows in Fig. 3). A specific key feature is the periodical difference in angle of inclination of the DWs: the left DW of the bright domains is more inclined toward the axial direction than the right DW (see Fig. 3(c)). Domains of this type have a tendency to be unstable and disappear. The hysteresis loop in Fig. 3(g) reflects the domain structure transformation. The sharp initial part of the hysteresis curve is related to nucleation of