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Study of surface magnetic structure in Co-based amorphous microwires by means of off-diagonal magnetoimpedance effect

A.A. Rakhmanov[a,*], A.S. Antonov[a], N.A. Buznikov[b], A.F. Prokoshin[a]

[a] *Institute for Theoretical and Applied Electrodynamics, Russian Academy of Sciences, Moscow 125412, Russia*
[b] *Research Center for Advanced Magnetic Materials, Chungnam National University, Daejeon 305-764, Republic of Korea*

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Abstract

A method for study of a surface magnetic structure in Co-based amorphous microwires with a negative magnetostriction is proposed. The method is based on the off-diagonal magnetoimpedance effect, which can be measured by the pick-up coil wound around the studied sample. The amplitude and phase of the signal in the pick-up coil were analyzed. It was observed that the amplitude and phase did not change at the moving of the pick-up coil along the sample, which denotes the uniform single-domain state at the surface of the studied microwires.

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Keywords: Amorphous microwires; Off-diagonal impedance; Domain structure

1. Introduction

The growing interest in amorphous microwires is related to their outstanding physical properties and their possible use in technological applications. One of the striking phenomena observed in such materials is the giant magnetoimpedance (GMI) effect, that is, a strong dependence of the sample impedance on an external magnetic field [1]. The effect is determined by the field-induced variation of a skin layer, which depends on surface microstructure of a sample. Thus, the interpretation of the GMI requires understanding of a domain structure in microwires.

The magnetization distribution in amorphous microwires is determined mainly by magnetoelastic interactions and, consequently, by the distribution of the quenching stresses appearing during the sample preparation. The magnetic properties of amorphous microwires are usually described in terms of the core–shell model [2–5]. In accordance with the model, a microwire with a negative magnetostriction has an outer shell with the circular easy magnetization axis and an inner core with the longitudinal easy magnetization axis. It is assumed usually that the outer shell of the amorphous microwires consists of the circular domains with opposite magnetization direction (the so-called bamboo domain structure) [2,4]. The study of the domain structure in such amorphous microwires is associated with great difficulties due to the absence of stray fields from the circular domains. The experimental results obtained by magneto-optical methods in partially polished samples [6] and in microwires with removed glass coating [7] confirm the existence of the bamboo domain structure. However, calculations have shown that the bamboo domain structure is energetically unfavorable for microwires with slightly negative magnetostriction, and the uniform magnetization distribution in the shell may exist for rather uniform microwires [8]. Therefore, surface domain structure of such microwires should be investigated further.

In this paper, a new method for study of the domain structure in Co-based amorphous microwires with a negative magnetostriction is proposed. The method is based on so-called off-diagonal magnetoimpedance effect

*Corresponding author. Tel.: +7 095 484 2310; fax: +7 095 484 2633.
E-mail address: rakh@newmail.ru (A.A. Rakhmanov).

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[9–11]. This effect is related to the cross-magnetization process and consists in as follows. Due to the existence of non-zero off-diagonal components of the permeability tensor, a high-frequency current causes the longitudinal magnetization variation. According to Faraday law, it induces the voltage in the pick-up coil wound around the microwire, which is proportional to the off-diagonal component of the impedance.

It should be noted that the off-diagonal impedance is sensitive to the surface domain structure. For microwires with the circular anisotropy, the pick-up coil voltage is non-zero within the range of the external field $H_e < H_a$, where H_a is the anisotropy field. If the microwire has the bamboo domain structure, the off-diagonal impedance observed is very small and irregular due to the contribution with opposite signs from the domains [12].

2. Experimental details

The experiments were performed on two types of samples with slightly negative magnetostriction. The first type was glass-coated $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous microwires. The diameter of the amorphous nucleus was 14 μm, and the coating thickness was 4.5 μm. The second type of the samples was tension-annealed amorphous microwires of the same composition and diameter 30 μm produced by Unitika Ltd. For measurements, the samples of length from 3 to 5 cm were used.

The schematic diagram of the experimental setup is shown in Fig. 1. The sinusoidal current with the amplitude of 0.5 mA was passed through the studied microwire. The current frequency was 1 MHz. In addition, the direct current I_{DC} could be passed through the sample to create the uniform magnetization at the microwire surface. The measurements were carried out in the presence of the longitudinal DC magnetic field of 0.2 Oe. The pick-up coil wound around the studied sample was 0.8 mm in diameter and 2 mm in length. The coil could be moved along the

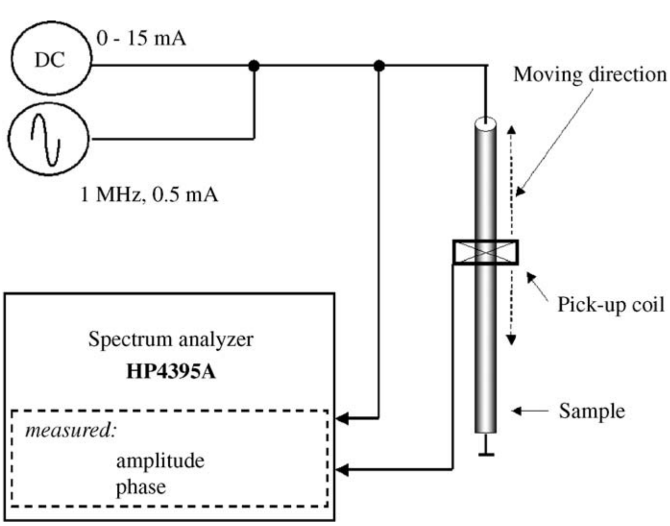

Fig. 1. Schematic diagram of the experimental setup.

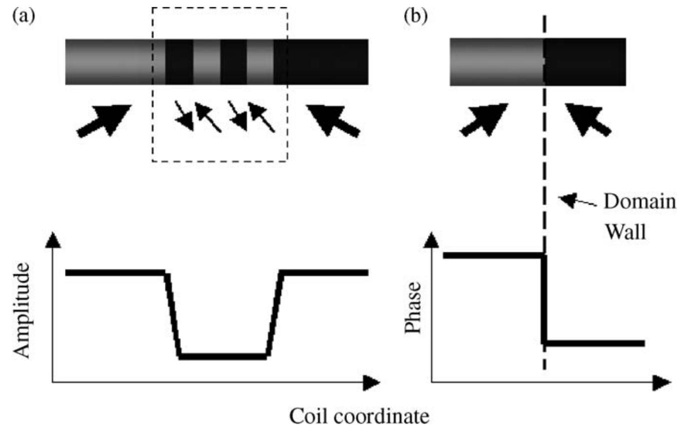

Fig. 2. Schematic representation of amplitude (a) and phase (b) of pick-up coil voltage.

microwire. The amplitude and phase of the coil signal were measured by using HP4395A spectrum analyzer as a function of the coil coordinate.

The principle of the method proposed is illustrated in Fig. 2. If the microwire has a single-domain structure, the amplitude of the pick-up coil voltage does not change at the moving of the coil along the sample. In the region of the bamboo domain structure, the voltage should tend to zero due to the opposite contribution of the domains as shown in Fig. 2(a). Furthermore, when the moving coil crosses the boundary between two domains, the phase difference between the voltage and driving current should change [see Fig. 2(b)]. Note that the spatial resolution of the method is restricted by the length of the pick-up coil and does not exceed its half-length. The domain structure with the dimensions less than 1 mm was averaged in the measurements.

3. Results and discussion

The coordinate dependences of the amplitude and phase of the pick-up coil voltage measured for the glass-coated microwire are shown in Fig. 3. At $I_{DC} = 0$, the amplitude and phase of the signal varies slightly with the coil coordinate, which allows one to conclude that the surface structure of the microwire is a single-domain. The significant changes were observed at the distance of 2.7 cm from the sample end, which indicates the presence of some defect. Note that visible defect of the glass coating can be observed at this point. Fig. 3 presents also the results of the measurements in the presence of the DC current. At $I_{DC} = 2$ mA, the signal phase differs slightly from that at $I_{DC} = 0$, whereas for $I_{DC} = -2$ mA the phase changes in sign. This is related to the change of the magnetization direction in the whole sample under the influence of the DC current.

To illustrate the effect of the domain structure on the signal in the pick-up coil, the artificial domain wall was created in the sample. This domain wall appeared, when short current pulses of the amplitude of 0.5 mA were