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Dynamics of closure domain structure in bistable ferromagnetic microwire

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ABSTRACT

Dynamics of closure domain structure in bistable glass-coated $Fe_{77.5}B_{15}Si_{7.5}$ amorphous ferromagnetic microwire was studied experimentally and theoretically. A new experiment for this study was proposed. The basic idea of this consisted in checking whether a well-defined rectangular magnetic field pulse applied to the microwire end can produce a stable and free domain wall in the microwire. A theoretical model previously used for describing the wall depinning process from the wire end was adapted for interpretation of our experimental results. Information about parameters of the potential well in which the wall is initially trapped as well as about wall dynamics was obtained. Values of these parameters are in good agreement with those obtained from different types of experiments.

1. Introduction

Amorphous ferromagnetic glass-coated microwires exhibit properties which attract attention from both physical and applications points of view [1,2]. Magnetic bistability of high magnetostrictive microwires is one of the characteristic features of these materials. Typically amorphous glass-coated microwires with positive magnetostriction display a core (axially magnetized)–shell (with radial domains) magnetic domain structure. The axially magnetized core occupies most of the sample volume. Stray fields at the wire ends cause closure domain structures to form. This is the place where magnetization reversal starts by depinning of a single domain wall which subsequently propagates along the microwire. The velocity of this wall reaches values as high as km/s, and its dynamics and intrinsic damping mechanisms have been thoroughly investigated recently [3–6]. Attention has also been paid to the study of critical fields at which the wall is depinned from the wire end [7,8] and to distribution of local nucleation fields of reversed domains along microwires [9,10]. Different ways of manipulation with a single domain wall, its dynamics in an inhomogeneous field and inertial mass determination have been subjects of recent works [10–12].

It was shown in [10] that a single wall moving along a bistable microwire can be stopped by an inhomogeneous magnetic field. This wall remains stable at approximately the same position even after all external magnetic fields are turned off. This fact gives rise to the possibility of carrying out the experiment presented in this paper. The basic idea of this consisted in checking whether a well-defined rectangular magnetic field pulse can produce a stable and free domain wall in the microwire. The relation between critical parameters of the field pulse (magnitude H_{pc}, length τ_c) for which a free wall is produced is a typical result of such an experiment. Comparison of the experimental results with an appropriate model can give information about the dynamics parameters of the microwire closure domain structure.

2. Experimental

The experimental set-up is shown in Fig. 1. A solenoid, 15 cm in length, generates a homogeneous field H along the magnetic wire. Part of the wire close to the left end was placed in a narrow magnetizing coil (pulse coil) 2 cm in length and 1 mm in diameter. This coil was connected to a function generator G, so that rectangular pulses of magnitude H_p and of length τ (see Fig. 2) could be generated in the pulse coil. The pick-up coil was connected to the input of an integrating amplifier IA, which enabled information to be obtained about the magnetic state of the part of the wire inside the pick-up coil [13].

The measurement procedure consisted of the following steps. First the sample was magnetically saturated in a negative axial field generated by the solenoid. After switching off this field a defined remanent state was obtained. Then the region of the wire close to its left end was magnetized by a positive rectangular field pulse generated by the pulse coil (see Fig. 2). In the next step a small positive axial field was generated by the solenoid. The magnitude of this field was large enough to move the existing

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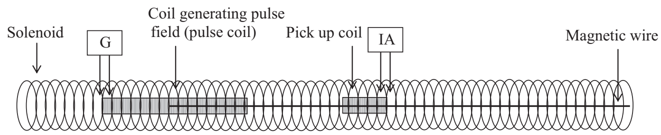

Fig. 1. Experimental set-up.

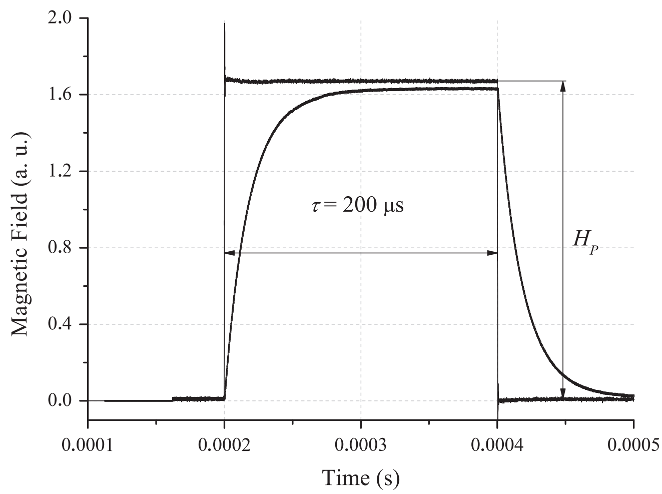

Fig. 2. Typical shapes of the field pulses. A rectangular pulse and a pulse with slow field change.

wall along the wire, but at the same time it was lower than the critical field needed for depinning the wall from the wire end [10]. Finally information about the wire magnetic state in the pick-up coil was obtained using the IA. If a free domain wall is produced by a field pulse then the magnetization reversal in the pick-up coil will be detected. Due to reasons which will be explained later, the measurements were also carried out for long field pulses with slow field change (see Fig. 2).

The critical parameters H_p, τ_c of the pulse which generates a free domain wall were obtained in the following way. In our experiment the length of the field pulse $\tau = \tau_c$ was kept constant and the magnitude of field pulse H_p was changed. For a given value of τ and H_p each measurement was repeated ten times and n gives the number of events in which a free domain wall was generated. An example of the measurement for one value of τ_c is depicted in Fig. 3. The way in which the corresponding critical magnitude of field pulse H_{pc} was derived is shown in this figure.

The measurements were performed on an amorphous ferromagnetic glass-coated $Fe_{77.5}B_{15}Si_{7.5}$ microwire. The diameter of the metallic nucleus was about 15 μm and the thickness of the glass layer was about 7 μm. The length of the sample used in the experiment was 12 cm.

The experimental relation between critical parameters of the field pulse (τ_c, H_{pc}) obtained using the procedures described above is shown in Fig. 4. As can be expected H_{pc} increases with decreasing τ_c. The minimum magnitude of the field pulse $H_{pc\,min}$ needed for the wall to be depinned from the wire end can be derived.

3. Discussion of experimental results

To interpret the experimental results shown in Fig. 4 we used the model proposed in [14]. This model has already been used for interpreting the depinning process in bistable glass-coated microwires [15,16]. It describes the remagnetization process in samples with a rectangular hysteresis loop in which a reversed domain already exists in the remanent state. The applied external

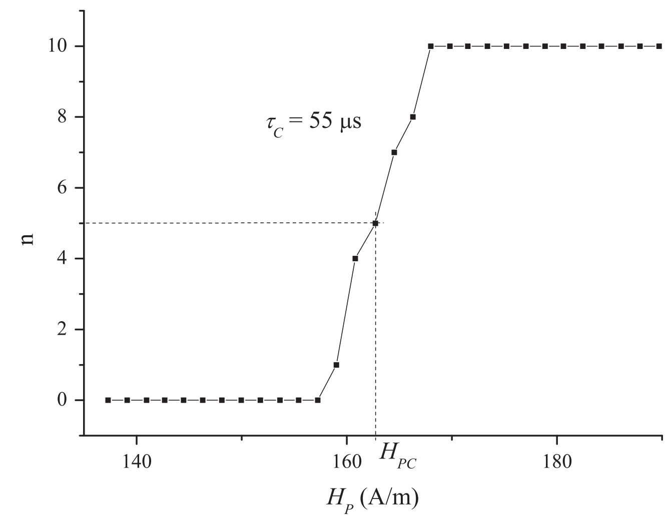

Fig. 3. Number of events n for which a free domain wall was generated by field pulse. H_{pc} was determined as H_p for which $n=5$.

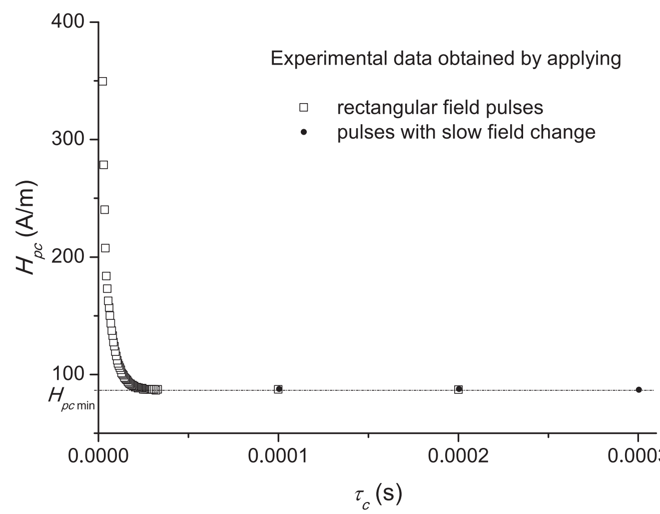

Fig. 4. The experimental relation between critical parameters of the field pulse τ_c and H_{pc} for rectangular field pulses and for pulses with a slow field change.

magnetic field causes the volume of the reverse domain to increase due to the domain boundary (wall) displacement. At a certain critical field the wall starts to propagate even if the applied field is not further increased.

We start with a brief summary of this model. The free energy of the wall can be expressed by the formula:

$$G(x) = W(x) - 2\mu_0 M_s H A x \quad (1)$$

where x is the wall position, M_s is the saturation magnetization, A is the area of the axial domain cross section, μ_0 is a magnetic constant and H is the applied magnetic field. The first term $W(x)$ in Eq. (1) can be expressed by a series in which only the first four terms are taken into account:

$$W(x) = W_0 + W'_0 x + \tfrac{1}{2} W''_0 x^2 + \tfrac{1}{6} W'''_0 x^3 \quad (2)$$

If the origin of the x-axis is chosen as the equilibrium position, then $\partial W/\partial x = 0$ at $x = 0$ and

$$W'_0 = 0 \quad (3)$$

At a certain critical field $H = H_{sw}$ the conditions $\partial G/\partial x = 0$ and $\partial^2 G/\partial x^2 = 0$ have to be fulfilled. From these conditions it is possible