STUDY OF DEPINNIG PROCESS IN BISTABLE FERROMAGNETIC MICROWIRE

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1. Introduction

Amorphous ferromagnetic wires with circular cross section are novel materials with unique magnetic properties [1]. Amorphous glass-coated Fe-based microwires are ferromagnetic materials showing bistable behavior. The characteristic feature of the magnetic bistability is the appearance of a rectangular hysteresis loop at low applied magnetic field. In these magnetic wires with a large positive magnetostriction the magnetoelastic anisotropy becomes dominant anisotropy and combined with shape anisotropy determines their magnetic properties. Magnetic reversal in these wires is typically by a large Barkhausen jump. Stray field at the end of the wire causes that closure domain structure is formed. This is the place where magnetization reversals start by depinning of a domain wall. It happens at a certain critical field and results in propagation of one (or two) domain wall along the wire. Dynamics of a single domain wall in this kind of magnetic microwires has been intensively studied recently [2, 3]. Attention was also paid to the study of critical fields at which the wall is depinned from the wire end [4, 5] and distribution of local nucleation fields of reversed domains along microwires [6, 7].

It was shown in [7] that a single wall moving along 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 is the basis of the experiment presented in this paper. The experimental set-up consists in placing the end of a microwire into small magnetizing coil which can produce well defined rectangular magnetic field pulse, and makes possible to measure critical parameters of the field pulse (magnitude H_p, length τ) for which a wall is depinned from the wire end and remains stable.

2. Experimental

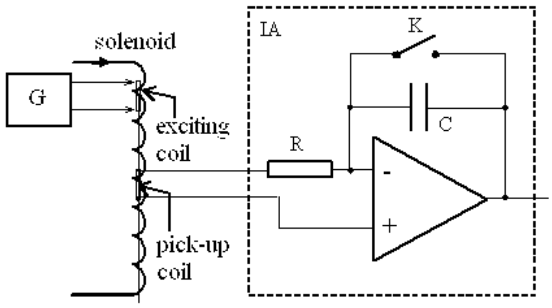

Fig.1: *Experimental set-up*

Measurements were performed on $Fe_{77.5}B_{15}Si_{7.5}$ amorphous ferromagnetic glass-coated wire of circular cross-section. The diameter of the metallic nucleus was about 10.2 μm and thickness of glass layer about 7.9 μm. The length of the sample used in experiment was 12 cm.

Typically magnetic reversal starts at the end of the wire. The experimental procedure proposed in [7] was modified in order to measure the critical fields at the end of the wire depending on the parameters of magnetic field pulse.

Experimental set-up is shown in Fig. 1. Solenoid, 15 cm in length, could generate homogeneous field H along the magnetic wire. A part of the wire close to the left end was placed in a narrow coil 1 cm in length and 1mm in diameter. It was connected to a function generator G and short rectangular pulses of magnitude H_p could be generated by this coil. The pick-up coil was connected to the input of an integrating amplifier IA, which gave possibility to obtain information about magnetic state of the part of the wire in the pick-up coil [8].

The measurement procedure consisted of the following steps. First the sample was magnetically saturated in negative axial field generated by the solenoid and then this field was switched off. In the remanent state obtained in this way a region of the wire close to its end was magnetized by rectangular field pulse. In the next step small positive axial field was generated by solenoid. Magnitude of this field was high enough to move the existing wall along the wire and at the same time lower then the critical field for depinning the wall from the wire end [7]. Finally the information about the magnetic state in the pick-up coil was obtained using IA [7, 8]. If a free domain wall was generated by field pulse the magnetization reversal in the pick-up coil was detected.

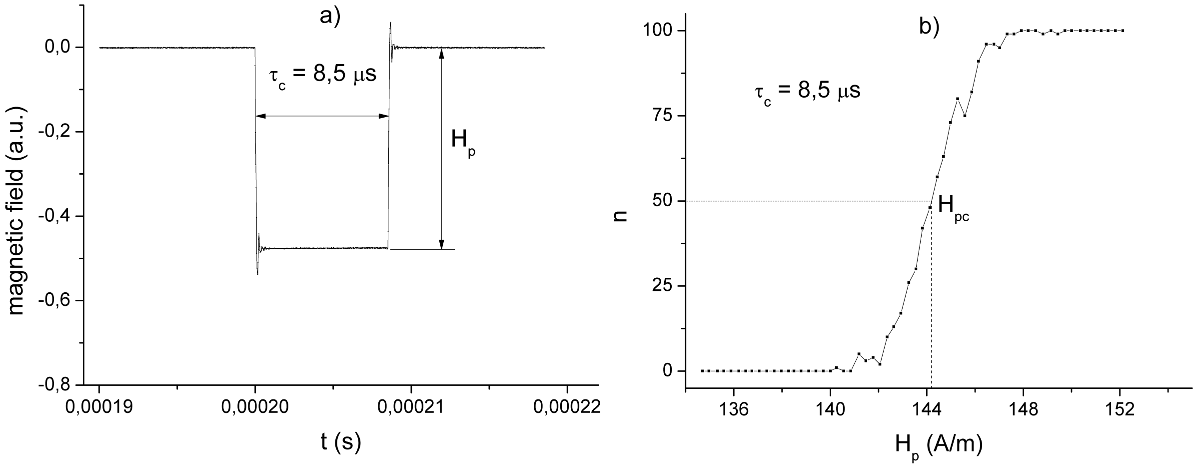

Fig.2: a) *Typical shape of the field pulse. b) Number of events n for which a free domain wall is generated by field pulse, the way how critical field H_{pc} was determined is shown.*

A length of the field pulse τ_c was kept constant and magnitude of field pulse H_p was changed. For a given value of τ_c each measurement was repeated one hundred times and n gives a number of cases for which free domain wall was generated. An example of measurement for one value of τ_c is depicted in Fig. 2a. The way how critical magnitude of the field pulse H_{pc} was derived is also shown in this figure.

The experimental relation between critical parameters of current pulse is shown in Fig. 3a. As can be expected H_{pc} increases with decreasing τ_c.

3. Discussion of experimental results

We use a simple model for interpretation of experimental curve in Fig. 3a. We consider that a domain wall is pinned at the wire end in parabolic potential well. The net force acting on the wall is

$$F_{tot} = -Kx + kH - \beta \frac{\mathrm{d}x}{\mathrm{d}t} \tag{1}$$

The equation of motion is

$$m\frac{\mathrm{d}^2(x)}{\mathrm{d}t^2} = -Kx + kH - \beta \frac{\mathrm{d}x}{\mathrm{d}t} \tag{2}$$

where K is positive constant and x is displacement of the wall from its equilibrium position, H is axial external field, β is damping coefficient, v is wall velocity, m is the inertial mass of the wall and

$$k = 2\mu_0 M_S A \tag{3}$$

where A is cross-section wall area and M_S is saturation magnetization.

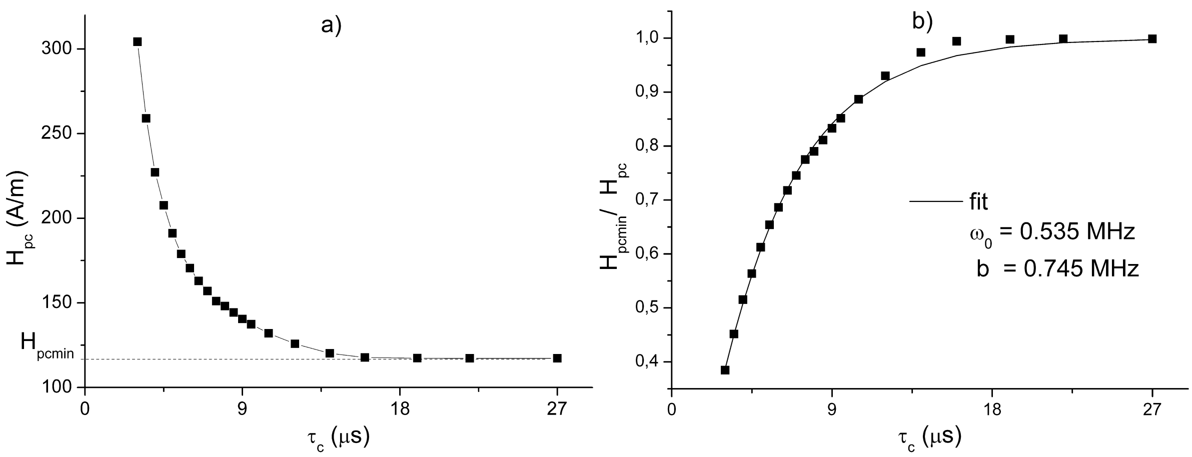

Fig.3: a) *Relation between critical parameters of the field pulse. b) Relation between critical parameters of the field pulse for inverse normalized critical magnitude of the field pulse, full line shows corresponding fitted curve*

In the framework of this model the wall is located at the bottom of potential well in the moment of switching on the field pulse. Its initial velocity is equal to zero. The inertial motion of the wall after switching off the field pulse was not taken into account. In other words we looked for solution of Eq.2 for which the wall moves from the bottom (x = 0) of the potential well to its border ($x = x_{\max}$) during the field pulse. Based on these assumptions the solution of Eq. 1 was found

$$\frac{H_{pc\min}}{H_{pc}} = \frac{1}{2\omega}(b-\omega)e^{-(b+\omega)\tau_c} - \frac{1}{2\omega}(b+\omega)e^{-(b-\omega)\tau_c} + 1 \tag{4}$$

where a large damping $\omega_0 < b$ ($\omega = \sqrt{b^2 - \omega_0^2}$, $2b = \frac{\beta}{m}$, $\omega_0^2 = \frac{K}{m}$) was assumed.

The value of minimum magnitude of pulse field $H_{pc\min}$ = 117 A/m was derived from experiment (see Fig. 3a). Experimental data were fitted to the function expressed by Eq.4 with ω_0 and b as fitting parameters. Result is shown in Fig. 3b.

From fitting parameters information about inertial mass of the wall

$$m = m_0 A = \frac{\mu_0 M_S}{b\lambda}\frac{\pi d^2}{4} = 1.207\times 10^{-16}\frac{\mu_0 M_s}{\lambda} \text{ (kg)} \tag{5}$$

and also about the half width of the potential well

$$x_{\max} = \frac{2bH_{pc\min}}{\omega_0^2}\lambda = 0{,}61\lambda \text{ (mm)} \tag{6}$$

can be obtained. In Eq. 4, 5 λ is wall mobility. Saturation polarisation $\mu_0 M_S$ = 1.56 T for this wire and the value of about 4 m^2/As was reported for wall mobility in a constant field in [9].

4. Conclusion

A new experiment was proposed for the study of depinning processes of a single domain wall from the end of bistable microwires. Comparison of experimental data with simple theoretical model gave the inertial mass of the wall of order 10^{-16} kg and the order of the width of potential well in which the wall is pinned at the end of the microwire is of the order of milimeter.

Acknowledgement

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References:

[1] H. Chiriac, T. A Ovari: *J. Magn. Magn. Mater.,* **323**, 2929 (2011).

[2] R. Varga, K. Richter, A. Zhukov, V. C. Larin: *IEEE Transaction on Magnetics*, **44**, 3925 (2008).

[3] V. Zhukova, J.M. Blanco, M. Ipatov, R. Varga, J. Gonzales, A. Zhukov: *Physica B*, **403**, 382 (2008).

[4] P. Gawronski, A. Zhukov, V. Zhukova, J. M. Blanco, J. Gonzales, K. Kulakowski: *Appl. Phys, Lett.,* **88**, 152507 (2006).

[5] R. Varga, A. Zhukov, M. Ipatov, J. M. Blanco, J. Gonzales, V. Zhukova, P. Vojtaník: *Phys. Rev. B,* **73**, 054408-1 (2006)

[6] M. Ipatov, V. Zhukova, A. Zvezdin, J. Gonzales, J.M. Blanco, A. Zhukov: *J. Supercond. Nov. Magn*., **24**, 851 (2011).

[7] J. Ziman, J. Onufer, M. Kladivová: *Magn. Magn. Mater.,* **323**, 3098 (2011).

[8] J. Ziman, B. Zagyi: *J. Magn. Magn. Mater*. **169,** 98 (1997).

[9] R. Varga, K. L. Garcia, M. Vázquez: *Physical Review Letters*, **94**, 017201-1 (2005).