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INFLUENCE OF STRESS AND DC CURRENT ON UNIDIRECTIONAL EFFECT IN DOMAIN WALL PROPAGATION

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It has been found out recently that domain wall mobility in glass-coated amorphous $Fe_{77,5}Si_{7,5}B_{15}$wire can be significantly different for cases when magnetization reversal caused by domain wall motion results in different orientation of magnetization, *ie* process of magnetization reversal runs easier when the sample is magnetized to one orientation of magnetization compared with the opposite one. This very interesting behaviour, so-called unidirectional effect is subject of the presented experimental study.

Domain wall mobility can be influenced by applied tensile stress and by circular magnetic field created by DC electric current flowing through the microwire. The experimental results obtained on samples with significant unidirectional effect show that both dependences, with higher and lower wall mobility, are influenced by applied stress and circular magnetic field. However, this influence is considerably stronger for dependence with higher mobility. Qualitative interpretation of this behaviour can be based on different damping mechanisms (spin relaxation or eddy currents) of domain wall motion. Dominance of spin relaxation damping can be responsible for stronger influence of stress as well as circular magnetic field, which is observed for dependences with higher mobility.

Keywords: microwire, amorphous ferromagnetic wire, dynamics of domain wall, magnetic anisotropy

1 INTRODUCTION

It was about three decades ago when glass-coated amorphous ferromagnetic microwires became the subject of intensive research in the field of soft magnetic materials. The glass-coated amorphous microwires with positive magnetostriction offer unique opportunity for the study of a single domain wall (DW) dynamics [1]. Understanding of magnetic domain wall dynamics is interesting from fundamental physics point of view and also from the point of view of technical applications [2, 3, 4].

Glass-coated amorphous microwires are prepared by Taylor – Ulitovsky technique. Rapid quenching of a melt during process of preparation results in characteristic distribution of internal stresses [5, 6]. Absence of magnetocrystalline anisotropy causes that domain structure of these materials is dominantly determined by magnetoelastic and shape anisotropy. As a result, the domain structure of microwires with positive magnetostriction consists of a large single axial magnetized domain in the central part of the metal core, which is surrounded by a small radially magnetized domain structure [7]. Closure domain structure is formed at both ends of the microwire in order to decrease stray field. The magnetization reversal in external magnetic field starts usually from the wire end by depinning of a single DW and its subsequent propagation along the microwire. For different applied fields, the average velocity of this wall can be measured by Sixtus-Tonks method and finally the dependence of wall velocity vs. applied field (v(H) dependence) can be obtained. It has already been reported that $v(H)$ dependences can be influenced by applied tensile stress [8, 9] and by circular magnetic field created by DC electric current [10] flowing through the microwire.

It has been found out recently that domain wall mobility ($v(H)$ dependences) of glass-coated amorphous $Fe_{77,5}Si_{7,5}B_{15}$ can be significantly different for cases when magnetization reversal caused by domain wall motion results in different orientation of magnetization [11]. In other words, the process of magnetization reversal runs easier when the sample is magnetized to one orientation of magnetization compared with the opposite one. This very interesting behaviour will be called as unidirectional effect.

In order to contribute to the discussion about interpretation of unidirectional effect we proposed new experimental set-up. We measured $v(H)$ dependences for different applied tensile stresses and for different circular magnetic fields created by DC electric current flowing through the microwire. In this paper we present results of the experiments which were carried out on sample with strong unidirectional effect.

2 EXPERIMENTAL

The DW dynamics was studied in amorphous glass-coated $Fe_{77,5}Si_{7,5}B_{15}$ microwire prepared by modified Taylor-Ulitovsky method. The length of the sample was 12 cm, diameter of metallic nucleus was about 15 μm and the thickness of glass coating was about 7.5 μm.

The experimental set-up used to measure DW velocity versus driving field dependences is depicted in Fig.1. It consists of four types of coils. The starting coil is 2 cm long with a diameter of 1.25 mm. A single DW from the wire end can be depinned by this coil and then the wall is shifted inside the driving coil. The driving coil is 6.5 cm long with a diameter of 0.5 mm. The distance between the

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end of driving coil and the first pick-up coil is big enough so that magnetic field can be switched on before the DW moves between the pick-up coils. In other words, the driving field is constant when the DW moves between the pair of pick-up coils with diameters of 1.25 mm. The blocking coil is 1 cm long with a diameter of 1.25 mm. The role of the blocking coil is to prevent a DW from moving from the opposite end of the wire.

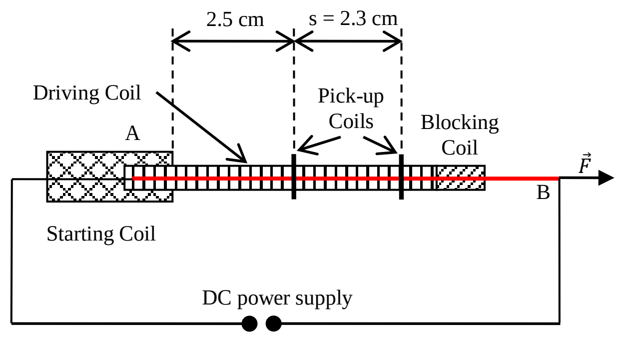

Fig. 1. Experimental set-up for velocity measurement, $\vec{F}$ is force applied to the end of the wire

The average velocity is measured using the Sixtus-Tonks method. Measurement of DW velocity for a given value of the driving field consists of the following procedures. The part of the wire inside the three magnetizing coils (starting coil, driving coil, blocking coil connected in series to a function generator) is magnetized in the same direction by rectangular magnetic field pulse. Then the starting coil is connected to function generator a field pulse of opposite sign is created. The parameters of this field pulse, magnitude and length, are such that a single DW is released from the left wire end and shifted inside the driving coil. By switching on a field of the same sign and specific amplitude in the driving coil, this DW is moved to the right along the wire. Average DW velocity is determined in a standard way from the time interval between signals induced in the pick-up coils measured by digital oscilloscope and the spacing between the pick-up coils.

For a given wire region (*ie* part of the wire between the pick-up coils) two different velocities can be measured. If the wall moves from end A to end B, two types of wall (head-to-head or tail-to-tail) and corresponding velocities can be distinguished (Fig.2). The letters A, B indicate the direction of the DW motion, index 1 means the head-to-head and index 2 the tail-to-tail type of wall, respectively. In our experimental arrangement the DW can move only from left to the right (from the end A to the end B velocity is marked as v_{AB}). If the wire is reversed, DW wall moves from the end B to the end A (velocity v_{BA}). The so-called unidirectional effect means that $v_{AB1}(H) \approx v_{BA2}(H)$ and $v_{AB2}(H) \approx v_{BA1}(H)$ [11].

The end of the wire located inside the starting coil was fixed. Tensile stress could be applied by a mechanical load attached to the outside end of wire. The applied stress was calculated considering the cross section of the sample (a metal core and a glass cover).

Thin copper wires were attached to the ends of the sample with silver paint and then connected to the DC current power supply. DC electric current was flowing through the microwire simultaneously with the driving magnetic field during the measurements of the DW velocity.

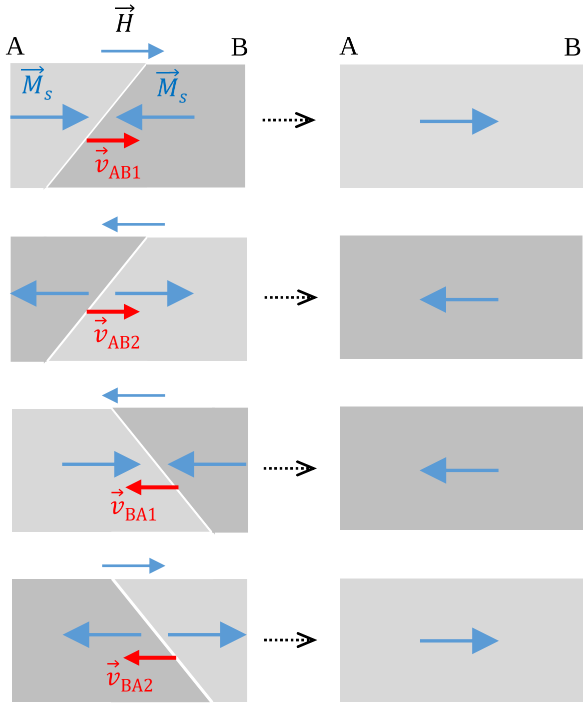

Fig. 2. Four possible magnetization reversal processes by propagation of a single domain wall along the bistable microwire

3 RESULTS AND DISCUSSION

A sample with strong unidirectional effect was chosen for our measurements. The $v(H)$ dependences shown in Fig. 3 are significantly different for cases when magnetization reversal caused by domain wall motion results in different orientation of magnetization. The main differences are observed at higher fields where values of wall velocity as well as mobility become significantly different.

In Fig. 3 the $v(H)$ dependences before (○, □) and after (+, ×) experiments with application of tensile stresses are depicted. In the same way the infuence of applied currents was checked. No irreversible changes in the $v(H)$ dependences were observed.

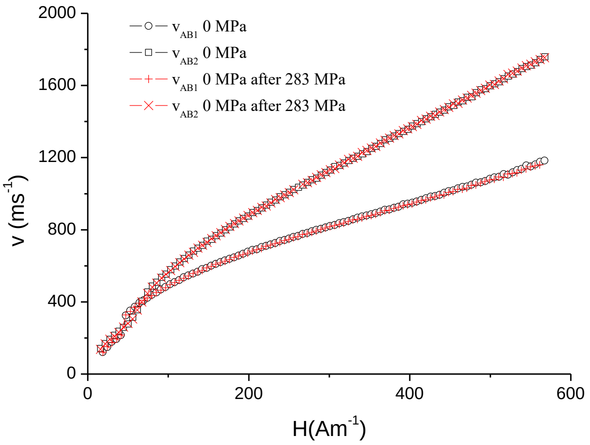

Fig. 3. DW velocity versus axial field dependences

As already mentioned, two different $v(H)$ dependences were observed. For simplification of further discussion the wall with higher mobility (○, +) will be called "fast" and with lower mobility (□, ×) will be called "slow".

The effect of tensile stress on $v(H)$ dependences for slow DW is shown in Fig. 4a and the same dependences for fast DW are shown in Fig. 4b. Tensile stress, which was applied simultaneously with driving field H causes decrease in wall mobility, and also in wall velocity, for both slow and fast domain walls. The $v(H)$ dependences for fast DW are more influenced by applied stress than the same dependences for slow DW.

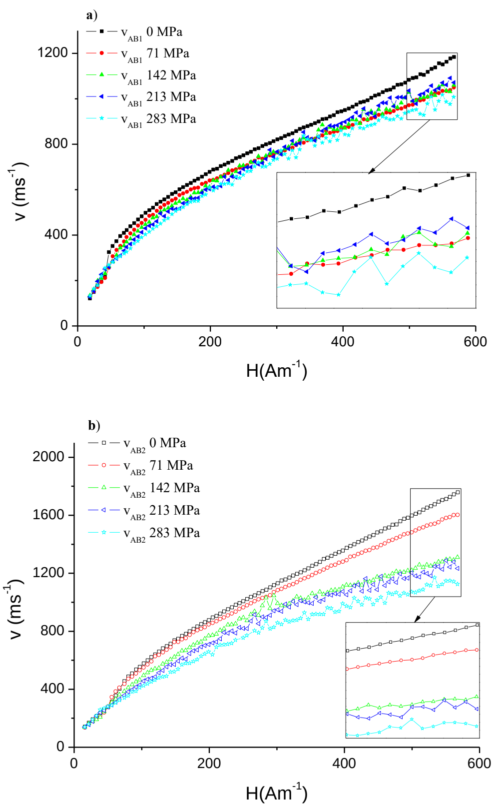

Fig. 4. DW velocity versus axial field dependences obtained in a sample for various values of tensile stress, for slow DW (a) and fast DW (b)

The effect of DC electric current on $v(H)$ dependences for slow DW and fast DW is shown in Fig. 5a and Fig. 5b, respectively. DC electric current was flowing through the microwire simultaneously with the driving magnetic field during the measurements of the DW velocity. It can be seen in Fig. 5 that for fast DW the DC electric current causes increase or decrease of wall mobility (or velocity), depending on the current direction. For slow DW this effect is similar, but in this case both current orientations cause an increase of wall mobility (or velocity). Current orientation which causes decrease of the wall mobility for fast DW causes smaller changes in the wall mobility in the case of slow DW. Similarly as for the case of applied stress v(H) dependences for fast DW are more influenced by magnitude of DC current than the same dependences for slow DW. It means that besides possible influence of helical anisotropy some additional mechanism is responsible for observed behaviour. Effects of tensile stress and DC electric current on $v(H)$ dependences have already been reported in work [9, 10].

The results of our study are in qualitative agreement with the results presented in these works. Main difference consists in the presence of unidirectional effect and in the new fact that fast DW is more strongly influenced by change of external conditions than the slow DW. Changes in wall mobility can depend on damping mechanism (eddy currents or spin relaxation) or on the wall geometry (its length).

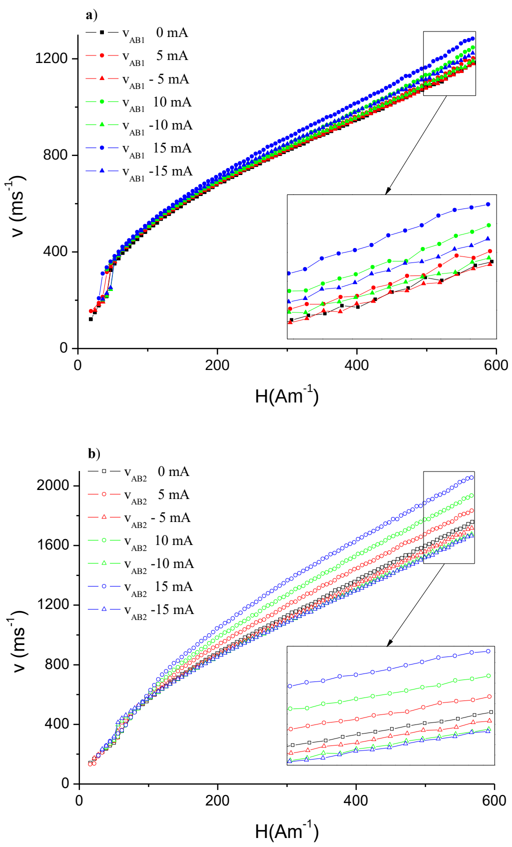

Fig. 5. DW velocity versus axial field dependences obtained in a sample for various values of the DC applied electric current, for slow DW (a) and fast DW (b)

Eddy currents do not depend on anisotropy, or wall energy, directly but only as a secondary effect of change in wall geometry. On the other hand, spin relaxation damping depends directly on anisotropy or wall energy and also on wall geometry. Based on these facts, it seems very probable that spin relaxation damping is more dominant for fast DW than for slow DW.

4 CONCLUSIONS

Domain wall velocity can be influenced by applied tensile stress and by circular magnetic field created by DC electric current flowing through the microwire. The experimental results obtained on samples with significant unidirectional effect show that velocity of fast and slow domain walls are influenced by applied stress and circular magnetic field. However, this influence is considerably stronger for fast domain walls. Qualitative interpretation of this behaviour can be based on different damping mechanisms of domain wall motion (spin relaxation or eddy currents). The dominance of spin relaxation damping can be responsible for stronger influence of stress and circular magnetic field observed for fast domain walls.

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