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MAGNETIZATION PROCESSES IN MAGNETIC MICROWIRES

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We have studied the domain wall dynamics in glass-coated magnetic microwires. Three different regimes were found. Firstly, the domain wall is pinned at the field lower then the dynamic coercivity and no propagation is observed. Secondly, the domain wall propagates in the series of intermittent jumps in the adiabatic regime as a result of its interaction with the defects presented in the sample. Finally, above the treshold field, the domain wall does not become pinned locally and its motion is characterized by the constant velocity , which is linearly dependent on the applied magnetic field

Keywords: magnetization process, Barkhausen jump, magnetic microwire

1 INTRODUCTION

In some magnetic devices, the information is transmitted along a magnetic wire by domain wall motion. The speed of the device is obviously linked to the domain wall velocity. Therefore, the domain wall propagation in small magnetic structures is of basic interest in last few years [1].

Amorphous glass-coated microwires with positive magnetostriction are characterized by a specific domain structure, which consists of the single domain with axial magnetization surrounded by the external domain structure with radial magnetization [2]. Small closure domains appear at the ends of the microwire in order to decrease the stray fields. As a result, magnetization process in axial direction runs through the depinning and subsequent propagation of the closure domain wall in one Large Barkhausen Jump. Although having almost bulk-like dimensions, their magnetization processes are very similar to that of nanostructures. Previous study of the magnetization processes in glass-coated microwires shows very interesting effects such a negative critical propagation field or new domain wall damping mechanism [3].

Here, we present the study of magnetization processes of the glass-coated microwires in the low field range in order to explain the unusual domain wall dynamics find previously in the glass-coated microwires.

2 THEORY

The domain wall motion in the defects-containing ferromagnetic matrix is similar to the oscillations in the mechanical system, wherein a body oscillates under an external force in a viscous medium [4]. Hence, by analogy, the equation for domain wall motion is:

$$m(d^2x/dt^2) + \beta(dx/dt) + \alpha x = 2M_sH \qquad (1)$$

where m is the effective domain wall mass, x is the domain wall position, β is damping coefficient, α is restoring force, M_s is the saturation magnetization and H is the applied magnetic field.

Assuming the domain wall propagates at a constant velocity, the linear dependence of the domain wall velocity v on the applied magnetic field H is obtained:

$$v=S(H-H_0) \qquad (2)$$

where S is the domain wall mobility ($S=2M_s/\beta$) and H_0 is the so called critical propagation field ($H_0=\alpha x/2M_s$), below which the domain wall propagation is not possible.

3 EXPERIMENTAL

The domain wall dynamics was studied on the amorphous glass-coated microwire of the composition $Co_{40}Fe_{36}Si_{11}B_{13}$ prepared by Taylor-Ulitovsky method.

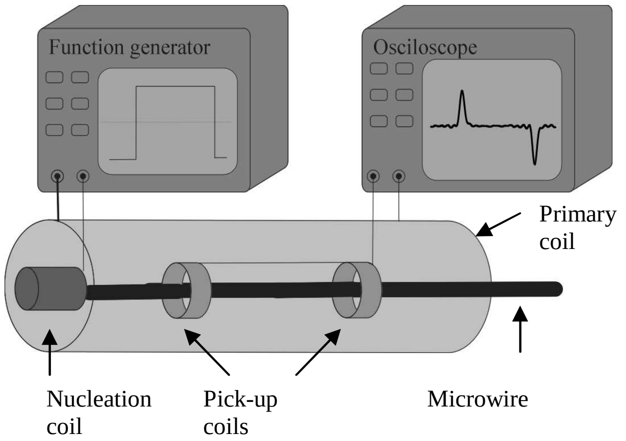

Fig. 1. Schematic diagram showing the experimental setup for the domain wall dynamics measurements

The microwire was 9cm long, with the diameter of metallic nucleus of 15 μm and total diameter of 27 μm. Measurements were performed using a Sixtus and Tonks-like experiment [5]. In our case, the set-up consists of three coaxial coils: the primary coil (10 cm long and 8 mm in diameter) and two secondary coils (3 mm long and 0.5 mm inner diameter) symmetrically placed and separated 6 cm. The primary coil generating the exciting field was fed by 10 Hz frequency AC square current creating a homogeneous field along the wire. Secondary coils are connected in series. Two sharp peaks are picked up at an oscilloscope upon passing of the propagating wall. The domain wall velocity is calculated as $v = L/(\Delta t)$, where L is the distance between pick up coils

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and Δt is the time interval between the two peaks. The system is placed inside a specially designed cryostat system enabling the measurement in the temperature range from 77 to 380 K.

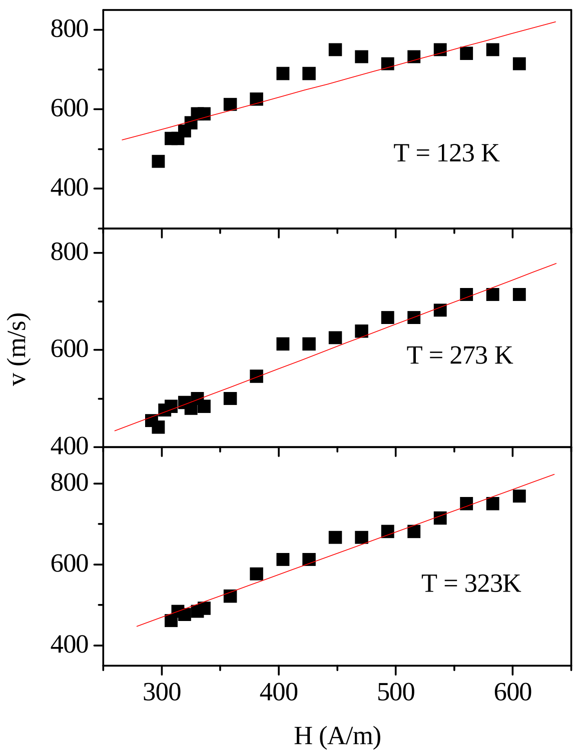

Fig. 2. Domain wall velocity as a function of magnetic field amplitude. The domain wall dynamics was measured without nucleation coil.

4 RESULTS AND DISCUSSION

According to Eq.2, the velocity of the propagating domain wall should be proportional to the amplitude of the applied homogeneous external field. Such dependence was found for magnetic wires and microwires [3, 6-8]. However, in the case of glass-coated microwires, the critical field for the domain wall propagation H_0 obtained by extrapolation (the curve over an applied field H of about 320 A/m) is negative. This predicts the possible domain wall propagation at the velocity v_0 ($v_0=v(H=0)$) even without applied field.

As can be seen in fig.2, the domain wall dynamics measured without nucleation coil in glass-coated FeCoSiB microwires also fulfil the linear dependence of the domain wall velocity on the applied external field. Similarly to ref.[3,8], the negative propagation field H_0 was found by extrapolation. The critical propagation field H_0 increases

Table1: Fitted parameters of the domain wall dynamics to Eq.2.

T (K)	H_0 (A/m)	S (m^2/As)	v_0 (m/s)
123	-385	0.8	308
273	-15.3	0.91	196
323	-147	1.05	154

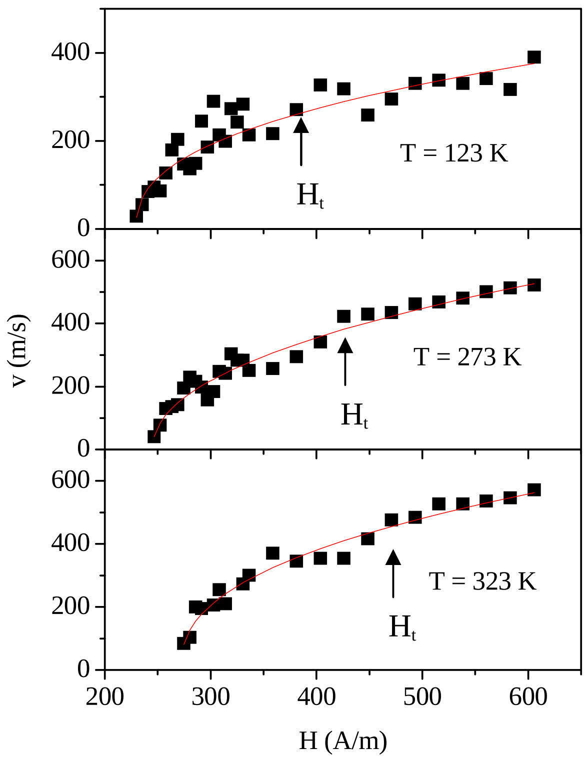

Fig. 3. Domain wall velocity as a function of magnetic field amplitude. The domain wall dynamics was measured with nucleation coil.

with the temperature and so does the domain wall mobility, too. The parameters obtained by fitting the data to eq.2 are shown in tab.1.

The problem of the domain wall dynamics measurements at low fields is that below the switching field of the closure domain wall no propagation is possible, since the domain wall is pinned at the end of the wire. In order to study the domain wall dynamics at low field and to approve the possible domain wall propagation without the applied external magnetic field we have employed the nucleation coil. The nucleation coil produces local magnetic field at the end of the wire, which is just above the switching field of the closure domain wall. This helps the domain wall to depinn end start to propagate along the wire.

The domain wall dynamics at low field measured with the help of the nucleation coil is shown in fig.3. As can be seen, the linear dependence of the domain wall velocity on the applied magnetic field is not valid below the switching field. Instead, the power law can successfully describe the

Table 2: Fitted parameters of the domain wall dynamics to Eq.3.

T (K)	H'_0 (A/m)	S´	q	H_t(A/m)
123	234	32.4	0.43	381
273	246	39.7	0.42	426
323	273	63.8	0.36	470

domain wall dynamics at low fields:

$$v=S'(H-H'_0)^q \quad (3)$$

where S' is so-called domain wall mobility parameter, H'_0 is the dynamic coercivity and q is the scaling parameter.

Such a power law results from the interaction of the propagating domain wall with the defects presented in the material, which different sources in the actual amorphous microwire have been described before [2,3]. In the low field limit, the domain wall motion is characterized by intermittent jumps from defect to defect. According to *ABBM* model [10], the local domain wall dynamics description is governed by the generalized eq. (2):

$$v=S(H-(H_{dm}+H_p)) \quad (4)$$

where the geometry dependent demagnetising field H_{dm} is separated from a random component, H_p, that includes all short-range counterfield contributions. The pinning field, H_p, is assumed to exhibit statistical properties governed by details of the local pinning potentials that inhibit domain wall motion. The average domain wall velocity v scales as is given by eq.3 [11].

The observed non-linear domain wall dynamics at low fields is not surprising. Our values of q correspond to that found by [12]. Although the scaling exponent should be universal for different scales and is given by the universality class [13], clear temperature dependence is deduced from our measurements (Tab.2) following the change of the defect structure in the microwire. Scaling exponent q reflects the correlation length of the domain wall with the defects. Due to their amorphous nature, the microwires contains a lot of defects such a local fluctuations of density, stress centres, etc… Moreover, due to the different expansion coefficient of the metallic nucleus and glass coating, the decrease of the temperature introduces additional strong stresses. As given in [11], the scaling exponent q should not exceed the value of ½. It is clear (tab.2) that although q changes with the temperature, it does not exceed the value of ½.

The scaling law is an universal law valid on a wide range of scales where cracking noise is detected: from meter (earthquake-tectonic plates rub past one to another), decimetres (movement of the car on the landscape full of holes) centimetres (splitting the piece of paper), millimetres (drop of the water moving around the dirty glass) down to the micrometer scale for the domain wall movement [13]. The same scaling law is also valid for the dislocation propagation along the material under small tension [14].

Anyway, the scaling law does not describe the dependence of the domain wall velocity on the applied magnetic field in the whole field region. Above some threshold field, H_t., the scaling law given by eq. 3 transforms into the linear eq. 2. The value of H_t is given by the maximum of the pinning field distribution amplitude. At the viscous regime, above H_t, the domain wall does not become pinned locally and it propagates in one continuous step without interaction with the local defects, in opposition to the adiabatic regime, below H_t. The temperature dependence of H_t follows the temperature dependence of the dynamic coercive field H'_0.

The extrapolated critical propagation field, H_0, takes negative values in the whole investigated temperature range. Alternatively, we introduce a modified expression for the wall velocity, $v(H_t)$, into eq. (2):

$$v = v(H_t)+ S\,(H-H_t) \quad (5)$$

Finally, an analytical description of the wall dynamics in the whole low-field range is given by:

$$v=\begin{cases} 0 & H<H_0 \\ S'(H-H_0)^q & H_0<H<H_t \\ v(H_t)+ S\,(H-H_t) & H_t<H \end{cases} \quad (6)$$

5 CONCLUSIONS

We have studied the magnetization processes in magnetic glass-coated microwires. Three different regimes were found in the domain wall dynamics in the glass-coated microwires. Firstly, the domain wall is pinned at the field lower then the dynamic coercivity and no propagation is observed. Secondly, the domain wall propagates in the series of intermittent jumps in the adiabatic regime as a result of its interaction with the defects presented in the sample. Finally, above the treshold field, the domain wall does not become pinned locally and its motion is characterized by the constant velocity, which is linearly dependent on the applied magnetic field.

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