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Influence of Thermal Treatment on Domain Wall Dynamics in Glass-Coated Microwires

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We have studied the effect of thermal treatment on amorphous glass-coated $\mathrm{Fe_{40}Si_{7.5}B_{15}}$ microwires. This microwire is characterized by transverse domain wall regime only, with maximum domain wall velocity of about 1500 m/s. Annealing at 200 °C slightly increases its transverse domain wall velocity, probably due to the reduction of mechanical stresses during the thermal annealing. Annealing at 300 °C leads to drastical increase of domain wall mobility and domain wall velocity of the transverse domain wall up to 2500 m/s. Moreover, vortex regime appears in this case. Thanks to it, maximum domain wall velocity of around 5000 m/s was observed.

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1. Introduction

The domain wall dynamics in amorphous glass-coated microwires is well known by very high domain wall velocities, which reach up to 10 km/s [1]. In particular, recently developed spintronic logic devices are based on the transport properties of uniaxial magnetic wires [2]. Speed at which the domain wall is able to run through wire is a key factor that determines the operating speed of these devices. Hence, a big attention is paid to find the mechanisms that increase the domain wall velocity of a given wire.

In the previous works the domain wall velocities in thin wire were increased by the presence of additional transverse anisotropy [3]. Here we show that the domain wall velocity in wire can be significantly increased by changing its intrinsic properties. A properly selected thermal annealing leads to the irreversible structure changes, which could result in the rapid increase of domain wall velocity.

2. Experimental

Amorphous glass-coated $\mathrm{Fe_{40}Si_{7.5}B_{15}}$ microwires were produced by the Taylor–Ulitovski method [4]. The diameter of metal core was 30 μm and thickness of glass coating was 15 μm. The length of all samples used in measurements was 10 cm.

The microwires were annealed for 1 h at temperatures 200 °C and 300 °C in order to observe the influence the various annealing temperatures. The domain wall dynamics was measured by the Sixtus–Tonks like setup. In order to avoid the additional effect of double annealing, the domain wall velocities were measured in two samples, each subjected to thermal annealing at different temperature.

3. Results and discussions

The domain wall velocity is described by linear equation of motion within the viscous model [5]:

$$v = S\,(H - H_0)\,,$$

where v is the domain wall velocity, H_0 is the critical field, S — the domain wall mobility and H — driven magnetic field. The high domain wall velocities in amorphous microwires are caused by two peculiarities: (1) negative critical fields (that could be explained by the interaction of the domain wall with stray fields of the microwire [6]) and (2) very high domain wall mobilities. According to the viscous model, the domain wall mobility could be evaluated as $S = 2\mu_0 M_\mathrm{S}/\beta$, where M_S denotes the saturation magnetization and β — the domain wall damping. In amorphous microwires, three contributions to the domain wall damping are recognized: (I) eddy current contribution inversely proportional to the resistivity of the material $\beta_\mathrm{e} \propto \rho^{-1}$, (II) magnetic relaxation damping directly proportional to the anisotropy $\beta_\mathrm{m} \propto \sqrt{K}$ (in our case the magnetoelastical one [5]), and (III) structural relaxation damping directly proportional to the concentration of free volumes $\beta_\mathrm{s} \propto c$. It has been shown [5] that the magnetic relaxation and the structural relaxation contributions are the dominant at room temperature in microwires. On the other hand, these domain wall dampings could be decreased by the thermal treatment. In FeSiB amorphous microwires, both structural and magnetic relaxation dampings are high, due to the amorphous state (high concentration c of free volumes) and the high magnetostriction of a given chemical composition (high anisotropy K). It results in relatively low maximum velocity, which reaches only 1–1.5 km/s (Figs. 1, 2 as-cast) as opposed to the others, where maximum velocity about 10 km/s has been obtained [1]. Here, we try to increase the domain wall velocity by decrease of (i) the structural relaxation and (ii) the magnetic relaxation domain wall

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dampings in order to underline their importance on high domain wall velocities in microwires.

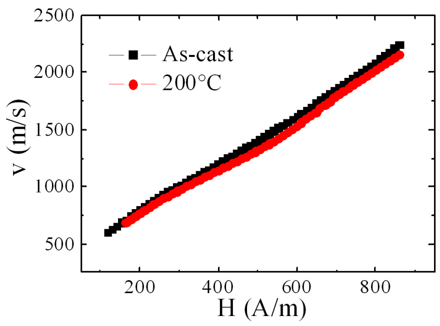

Fig. 1. The dependence of the domain wall velocity on driving field before and after thermal treatment at 200 °C of FeSiB microwire.

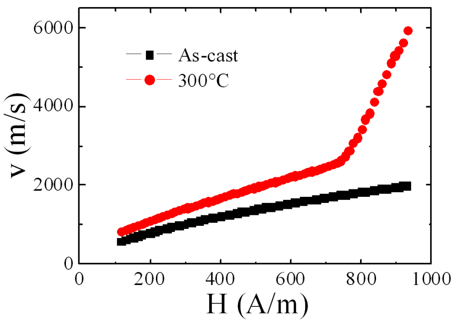

Fig. 2. The dependence of the domain wall velocity on driving field before and after thermal treatment at 300 °C of FeSiB microwire.

As it is seen in Fig. 1, annealing at 200 °C does not change neither the critical field nor domain wall velocity. This is in a good agreement with previous attempts [7], where annealing of FeSiB wires at 200 °C caused only 10% increase of domain wall velocity. Annealing at this temperature leads to the reversible structure changes only. Such result has been obtained in several measurements of FeSiB alloys, where annealing at 200 °C did not change its magnetic properties in comparison to the as-cast state [8].

On contrary to the annealing at 200 °C, annealing at the higher temperature 300 °C leads to the two significant effects (Fig. 2): (1) remarkable increase of domain wall mobility of primary regime and (2) introduction of a new, secondary regime (with positive critical field). The increase of domain wall mobility is caused by decrease of magnetic relaxation damping (caused by relaxation of internal stresses) and by decrease of structure relaxation damping (caused by annealing out of free volumes). It has been shown previously that regime with positive critical field is caused by change of the internal domain wall structure from the transversal to the vortex one [3]. On contrary to the transversal domain wall, the structure of the vortex domain wall contains higher amount of magnetic moments oriented out of easy axis. Hence, the magnetoelastic part of the total domain wall energy is more important in the vortex domain wall in comparison to the transversal one. Since the thermal treatment at 300 °C decreases the residual internal stresses, the magnetoelastic part of the energy of the domain wall then also decreases, which allows one to form the vortex domain wall, even in the wire, where the vortex domain wall has not been present before thermal treatment.

4. Conclusions

In conclusion, we compared the effect of thermal annealing on domain wall dynamics in high magnetostriction FeSiB microwires. Annealing at 200 °C temperature does not change the domain wall dynamics significantly. On the other hand, properly selected higher temperature drastically decreases the anisotropy as well as the free volumes, which leads to the increase of domain wall mobility. Moreover, decrease of magnetoelastic part of the total domain wall energy allows appearing vortex domain wall. Thanks to it, the impact of thermal treatment on maximum velocities is even more significant.

Acknowledgments

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