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Magnetic Properties of Glass-Coated FeWB Microwires

P. Klein[a,*], R. Varga[a], R. El Kammouni[b] and M. Vazquez[b]

[a]Institute of Physics, Faculty of Sciences, P.J. Safarik University, Park Angelinum 9, 041 54 Košice, Slovakia

[b]Institute of Material Science of Madrid, CSIC, 28049 Madrid, Spain

We have studied magnetization process in amorphous bistable $Fe_{80}W_3B_{17}$ microwires with reduced Curie temperature. High mechanical stresses from glass-coating, induced during production process, result in high switching field. Reducing the length of microwire, the switching field decreases as a result of reduction of magnetoelastic anisotropy. Moreover, the decrease of magnetoelastic anisotropy results in a complex temperature dependence of the switching field. On the other hand, strong variations of the switching field with temperature can be employed in miniaturised temperature sensor.

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1. Introduction

Amorphous glass-coated microwires are modern materials that attract attention of scientists and engineers in last decades. They consist of metallic nucleus of diameter 100 nm–50 μm and glass-coating with thickness of 2-20 μm. Due to their dimensions they can be employed for contactless sensing of magnetic field, temperature, mechanical stress, position etc. [1,2].

Glass-coated microwires are produced by drawing and quenching of molten master alloy together with the glass – the process that introduces strong and complex stress distribution in metallic nucleus. Their magnetization reversal process runs through the single Barkhausen jump at the field called switching field H_{sw}. The switching field is sensitive to external parameters like temperature or mechanical stress, that allows employment of microwires for miniature sensor applications.

One possible way to increase the sensitivity of switching field is to employ the materials with low Curie temperature [3]. Below Curie temperature, the magnetic characteristics (magnetization, magnetic anisotropy) are strongly varying.

In this report, we deal with the temperature dependence of amorphous $Fe_{80}W_3B_{17}$ microwire. Wolfram is known to decrease the Curie temperature of amorphous alloys [4]. Hence, magnetoelastic anisotropy decreases, too. As a result, strong and complex variation of the switching field with temperature is observed.

2. Experimental

The study has been performed on glass-coated amorphous microwires with nominal composition of $Fe_{80}W_3B_{17}$, prepared by the modified Taylor-Ulitovsky technique. The diameter of the metallic core was 12.5 μm and the total diameter 25 μm. In order to decrease the strong stresses introduced during microwire production, all samples have been annealed at 300^{o}C for 1 h and slowly cooled down to room temperature (for 12 h) to relax the stresses introduced by glass due to different thermal expansion coefficients of glass coating and metallic nucleus.

The length of the sample used for measurements varied from 1.3 to 12 cm.

The switching field has been measured by induction method at the frequency 1000 Hz with maximum amplitude 1000 A/m.

More details on the experimental setup can be found elsewhere [5].

3. Results and discussion

Due to existence of two contributions to the domain wall potential of the closure domain wall in amorphous microwires, the switching field H_{sw} of bistable microwires can be satisfactorily described by two contributions. Firstly, it is the structural relaxation contribution [5]. However, it has been shown that W hinders significantly the structural relaxation in amorphous FeB alloys [4]. In order to avoid this contribution completely, the measuring frequency has been set to 1000 Hz as this contribution is practically negligible at higher measuring frequencies [5]. On the other hand, magnetoelastic contribution of the switching field is dominant at high frequencies. It is proportional to the energy of closure domain wall [6]:

$$H_{sw}^{\sigma} \approx \frac{\sqrt{A\lambda_S\sigma}}{\mu_0 M_S}, \qquad (1)$$

where A is the exchange constant, λ_S is the saturation magnetostriction, μ_0 is magnetic permeability of vacuum and σ is given by the sum of the stresses introduced during production process (σ_i) together with stress applied on the microwire by the glass due to different thermal expansion coefficients of metallic nucleus and glass-coating (σ_a).

The stresses $\sigma_a(T)$ arising from the different thermal expansion coefficient of metallic nucleus α_m and glass

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[*] corresponding author; e-mail: peter.klein@upjs.sk

coating α_g are proportional to the temperature T:

$$\sigma_a(T) \approx E_{gl}(\alpha_m - \alpha_g)\Delta T, \qquad (2)$$

where E_{gl} is Young modulus of the glass.

The temperature dependence of magnetoelastic contribution is mainly given by the temperature dependence of the stresses introduced by the glass on the metallic nucleus σ_a.

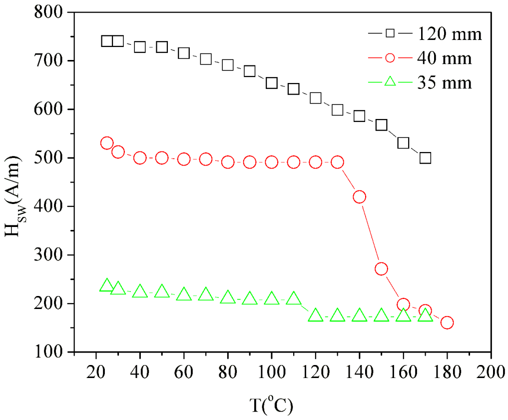

Fig. 1. Temperature dependence of the switching field H$_{sw}$ for long FeWB microwires annealed at 300 ^{o}C.

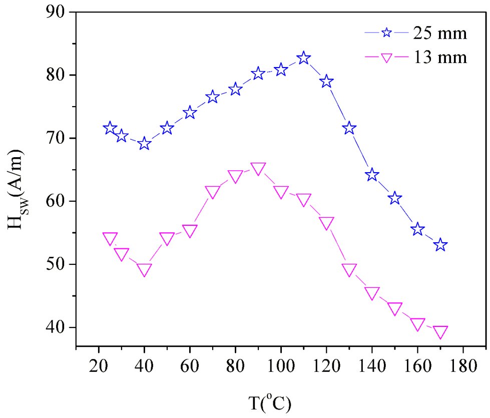

Fig. 2. Temperature dependence of the switching field H$_{sw}$ for short FeWB microwires annealed at 300 ^{o}C.

Temperature dependence of the switching field H_{sw} for FeWB microwires with different lengths is shown in Fig. 1. As a result of strong stresses introduced during microwires production, the amplitude of the switching field is high ~750 A/m at room temperature for longest microwire (120 mm). As a result of reduction of the stresses applied by glass-coating, $\sigma_a(T)$, the switching field decreases with temperature monotonously.

The decrease of the length of microwire leads to the switching field reduction down to 540 A/m for microwire of length of 40 mm. The glass-coating induces high mechanical stresses on the metallic core. These stresses decrease significantly with decreasing the length of the sample. Moreover, shape anisotropy (that decreases with decreasing length of the microwire) plays also very important role. On the other hand, the temperature dependence of the switching field becomes more complex, showing strong decrease above 130 ^{o}C. At this temperature, the anisotropy decreases steeply as it approaches the Curie temperature (this microwire looses bistability above 180 ^{o}C).

The effect is even more enhanced when the microwire's length decreases to 35 mm. The switching field decreases down to 240 A/m and its decrease shifts down to 110 ^{o}C.

However, situation is more complex for very short FeWB microwires with length 25 mm and 13 mm (see Fig. 2). The switching field decreases steeply down to 72 and 55 A/m respectively due to much smaller mechanical stresses applied by glass-coating.

Moreover, the temperature dependence of switching field becomes complex. Firstly, switching field increases with increasing temperature up to 110 ^{o}C and 90 ^{o}C for 25 mm and 13 mm long microwires, respectively. Then, switching field decreases with increasing temperature mainly due to low value of the Curie temperature.

Such temperature dependence approves that magnetoelastic anisotropy is no more dominant. However, strong variations of the switching field could be employed for sensing the temperature.

4. Conclusions

In this contribution, we have studied the temperature dependence of the switching field in amorphous FeWB microwires with low Curie temperature. It is shown that decrease of the microwire's length significantly decreases magnetoelastic anisotropy that results in a complex temperature dependence of the switching field. Such strong variations can be employed for sensing the temperature in miniature applications.

Acknowledgments

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