Giant Magnetoimpedance Microwires for Sensor Applications

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Abstract

The influence of post-processing (annealing and stress-annealing) on the Giant magnetoimpedance (GMI) effect in thin magnetic microwires is reviewed. High GMI effect has been observed in Co-rich magnetic microwires with vanishing magnetostriction coefficient. Post-processing including annealing or stress-annealing at adequate conditions allows further improvement of GMI effect in Co-rich magnetic microwires.

1. Introduction

Magnetic and magnetoelastic sensors and smart composites utilizing soft magnetic wires with Giant Magneto-impedance present excellent features including extremely high sensitivity to external stimuli: i.e. magnetic field, stress or temperature making them suitable for many applications [1]-[3]. Most of the emerging applications require materials with reduced dimensionality and excellent soft magnetic properties, superior mechanical properties, enhanced corrosion resistance and biocompatibility [1],[4].

Generally, amorphous magnetic wires present the best combination of soft magnetic properties and superior mechanical characteristics [4],[5]. The other functional properties, like reduced dimensionality, improved corrosion resistance and biocompatibility can be achieved in amorphous microwires coated by flexible and insulating glass-coating [4], [5]. Therefore, studies of GMI effect in amorphous glass-coated microwires gained considerable attention since the 90-s [5].

The magnetoelastic anisotropy is one of the most important parameters that determine the magnetic properties [4],[5]. The most common way to tune the magnetoelastic anisotropy is the selection of proper chemical composition with nearly-zero magnetostriction coefficient, λs. Indeed, vanishing λs-value in amorphous alloys can be achieved choosing Co_xFe_{1-x} ($0 \leq x \leq 1$) alloys with x about 0.03-0.08 [5]. However, theoretical maximum GMI effect is above 3000% (i.e few times larger than GMI ratio values reported experimentally) [4,5]

Consequently, we present our recent experimental results on post- processing of magnetic microwires with aim to achieve better magnetic softness and GMI effect.

2. Materials and methods

We selected typical $Fe_{3.6}Co_{69.2}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_{1.2}$ alloys with vanishing λs-value. We used micro-strip sample holder placed inside a sufficiently long solenoid that creates a homogeneous magnetic field, H. The sample impedance, Z, was measured using vector network analyzer from the reflection coefficient S_{11} using expression:

$$Z = Z_0 \frac{(1+S_{11})}{(1-S_{11})} \quad (1)$$

where Z_0=50 Ohm is the characteristic impedance of the coaxial line [6]. Described technique allows measuring of the GMI effect in extended frequency, *f*, range up to GHz frequencies. For GMI characterization we used GMI ratio, $\Delta Z/Z$, defined as:

$$\Delta Z/Z = [Z(H) - Z(H_{max})]/Z(H_{max}) \quad (2)$$

where H_{max} is the maximum axial *DC* magnetic field (usually up to few kA/m).

Hysteresis loops have been measured using fluxmetric method [9]. We represent the normalized magnetization, M/M_0 versus magnetic field, *H*, where *M* is the magnetic moment at given magnetic field and M_0 is the magnetic moment of the sample at the maximum magnetic field amplitude, H_m.

3. Results and discussion

As-prepared microwires present linear hysteresis loops with low H_c (see Fig. 1a). Similarly to other Co-rich

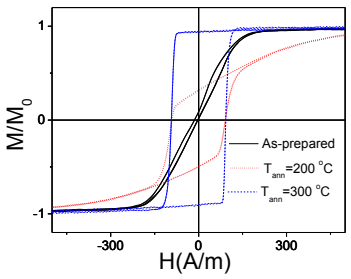

Figure 1. Hysteresis loops of as-prepared (a) and annealed at 200^{0}C, (b), and 300 ^{o}C (c) $Fe_{3.6}Co_{69.2}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_1$ microwires.

microwires with vanishing λs –values $Fe_{3.6}Co_{69.2}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_{1.2}$ microwire presents drastic magnetic hardening upon annealing: an order of magnitude coercivity, H_c, rising from 5 A/m up to 90 A/m (see Fig. 1b,c). However, GMI ratio of $Fe_{3.6}Co_{69.2}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_1$ microwires annealed at 300 °C is considerably higher (see Fig. 2).

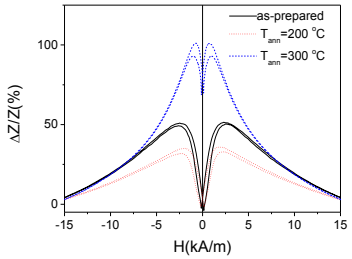

Figure 2. *ΔZ/Z (H)* dependencies of as-prepared and annealed $Fe_{3.6}Co_{69.2}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_{1.2}$ microwires measured at 500 MHz.

Stress-annealing allows to reduce considerably the H_c-value (see Fig.3). However, at selected annealing conditions

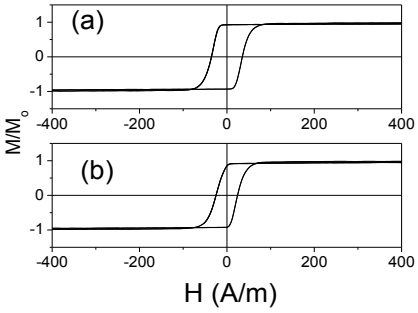

Figure 3. Hysteresis loops of $Fe_{3.6}Co_{69.2}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_{1.2}$ microwires annealed at T_{ann}=300 °C for t_{ann}=1 h under 118 (a) and 236 (b) MPa.

(Tann=300 °C, tann= 1 h) the hysteresis loops shape remains rectangular. As regarding the GMI effect, all stress-annealed Co-rich microwires present a remarkable GMI ratio improvement (see comparison in Fig. 4 (a)): for f=200 MHz more than double GMI ratio improvement is observed almost for all stress-annealed samples. As can be appreciated from the frequency dependence of maximum GMI ratio, $\Delta Z/Z_m(f)$, dependencies shown in Fig. 4 (b) this $\Delta Z/Z_m$ improvement is observed for all frequency range (up to 1 GHz). It is interesting that the optimum frequency for as-prepared sample is about 100 MHz, however, for stress-annealed samples the optimal frequency shifts to about 150 MHz.

Accordingly, stress annealing of Co-rich microwires allowed considerable GMI effect improvement

4. Conclusions

We observed that the stress-annealing allows remarkable improvement of GMI effect in Co-rich microwires: about 100% GMI ratio improvement is demonstrated.

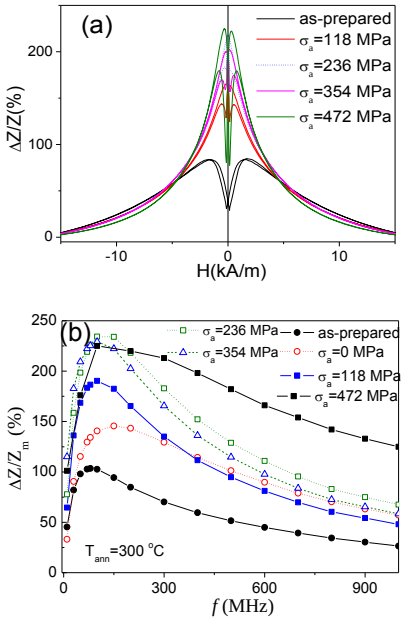

Figure 4. *ΔZ/Z(H)* dependences of as-prepared and stress-annealed at T_{ann} = 300 °C samples at different σ_a measured at 200 MHz (a) and $\Delta Z/Z_m(f)$ dependencies for the same samples (b).

The future scope of our research will be focused on magnetic wires miniaturization and further development of appropriate post-processing.

References

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