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Magnetoimpedance Effect in Field Annealed $(FeNi)_{78}Nb_7B_{15}$ Amorphous and Nanocrystalline Bilayer Ribbons

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The influence of the magnetic field annealing on the magnetoimpedance effect has been investigated in rapidly quenched $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ monolayer and bilayer thin ribbons. The highest impedance ratio value $(\Delta Z/Z)_{max} = 72\%$ and the maximum field sensitivity $\eta_{max} = 12$ %/Oe was obtained in the bilayer ribbon, annealed under longitudinal magnetic field at 773 K that exhibited nanocrystalline structure. The higher values of $(\Delta Z/Z)_{max}$ in bilayer ribbons, as compared to their monolayer counterparts, are attributed to the increased ratio of their thickness to the penetration depth.

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1. Introduction

The giant magnetoimpedance effect (GMI) is attracting a great deal of scientific and technological interest because of its applications for magnetic field, current, or stress sensors [1]. GMI sensors provide several advantages; mainly they have high sensitivity, high thermal stability as well as small dimensions. Among the most frequently used GMI materials are Fe- and Co-based amorphous and nanocrystalline alloys [2]. An appropriate annealing of Fe-based amorphous ribbons, which is connected with improved magnetic softness, leads to the increase of the GMI [1]. This work deals with the experimental study of the influence of longitudinal as well as transversal magnetic field annealing on the GMI effect in $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ in the form of monolayer and bilayer ribbons.

2. Experimental

The amorphous monolayer ribbons were prepared by the conventional planar flow casting method. In the case of the bilayers, a single crucible with two nozzles close to each other and with a partition between them, forming two separate vessels, was used [3]. Such an arrangement has allowed us to obtain ribbons with two layers of the same composition, one on top of the other, along the whole ribbon length. The thickness of monolayer and bilayer $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ ribbons was determined to be 25 μm and 37 μm, respectively. Pieces of 60 mm long and 6 mm wide of as - quenched ribbons were isothermally annealed at temperatures 673 K or 773 K for 1 hour, leading to thermally relaxed amorphous or nanocrystalline state. During the annealing, longitudinal (LF) as well as transversal (TF) magnetic field was applied with intensity of 40 kA/m or 640 kA/m, respectively. Reference samples were annealed in zero magnetic field (ZF).

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GMI measurements were performed by Impedance analyzer Agilent 4294A over a frequency range 0.1–10 MHz.

The relative change of the impedance Z with applied field H was calculated as:

$$\Delta Z/Z = [(Z(H) - Z(H_{max}))/Z(H_{max})] \times 100\%, \quad (1)$$

where H_{max} is the maximum field used (10 kA/m in our case). GMI sensitivity is defined as the derivative of the GMI ratio with respect to the external DC magnetic field:

$$\eta = \mathrm{d}(\Delta Z/Z)/\mathrm{d}H. \quad (2)$$

The GMI data was supplemented by differential scanning calorimetry (DSC), transmission electron microscopy (TEM) as well as by magnetization and hysteresis loop measurements.

3. Results and discussion

The DSC calorimetry confirmed the onset of primary and secondary crystallization at temperatures 736 K and 877 K, respectively. The changes in microstructure upon annealing were examined by TEM. The samples annealed at 673 K remained fully amorphous. On the other hand, the annealing at 773 K resulted in formation of the nanocrystalline FeNi grains embedded in amorphous matrix with typical dimensions being 5–10 nm.

The Curie temperature of the amorphous $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ alloy determined from temperature dependence of the magnetization was found to be around 493 K. The effect of thermal processing under external magnetic field was examined by the hysteresis loop measurements. Heat treatment under LF-conditions resulted for all samples in a marked reduction of the coercivity as compared to ZF-annealing. The lowest coercivity value was found for the LF-annealed, thermally relaxed amorphous sample, where H_C reached ~ 0.7 A/m. Sheared loops with good field linearity were achieved after TF - annealing similarly as in [4, 5].

Figure 1 shows that the GMI characteristics exhibit single or double peak structure depending on the orientation of external magnetic field applied during the heat treatment. The position of peaks at GMI curve corre-

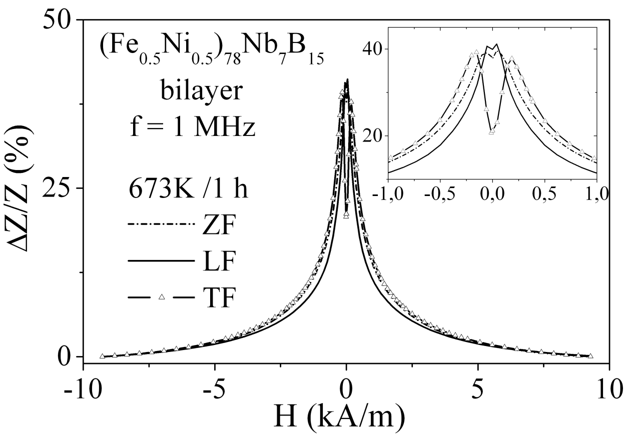

Fig. 1. Field dependence of magnetoimpedance ratio for amorphous $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ bilayer annealed at 673 K.

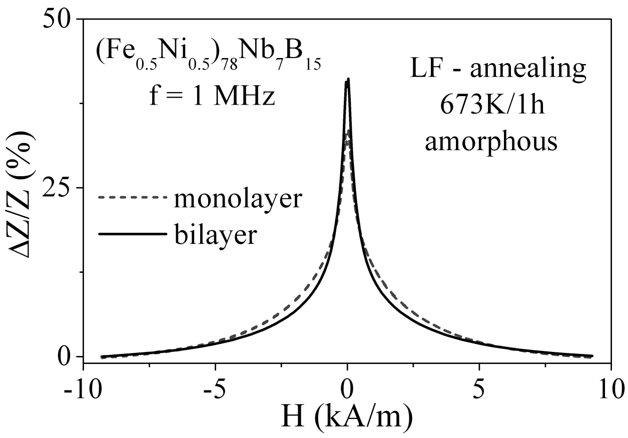

Fig. 2. Field dependence of magnetoimpedance ratio for amorphous $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ after LF-annealing at 673 K.

sponds to an effective magnetic anisotropy field, induced during the field annealing [1]. In the case of TF-annealed samples, a clear double peak GMI response is visible in the inset of Fig. 1. Here, two maxima are observed at the positions where the external dc magnetic field, applied in the longitudinal direction, reaches the transverse anisotropy field, $\pm H_k$. On the other hand, longitudinal magnetic anisotropy induced by LF-annealing, leads to single peak behaviour of the magnetoimpedance, in accordance with [6].

Figure 2 shows the measured $\Delta Z/Z(H)$ dependences for mono and bilayer ribbons after field annealing at 673 K in longitudinal magnetic field. The comparison of these two curves demonstrates that the bilayer ribbons in thermally relaxed amorphous state exhibit higher values of GMI ratio. The difference between the magnetoimpedance ratio values of monolayer and bilayer is even more pronounced after LF-annealing at 773 K. Annealing at this temperature leads to a transformation of sample from amorphous to nanocrystalline state. The maximum impedance ratio $(\Delta Z/Z)_{max}$ for nanocrystalline bilayer reaches 72% and maximum field sensitivity η_{max} is 12 %/Oe. These values are much higher than those for the monolayer, where $(\Delta Z/Z)_{max}$ is 45% and η_{max} is 8 %/Oe. The higher $(\Delta Z/Z)_{max}$ values for thicker bilayers can be explained by the increased ratio of the thickness to the penetration depth, as compared to their thinner monolayer counterparts [1].

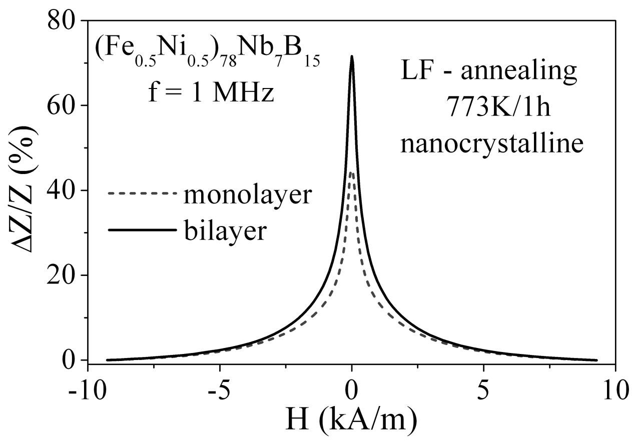

Fig. 3. Field dependence of magnetoimpedance ratio for nanocrystalline $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ after LF-annealing at 773 K.

4. Conclusions

It was shown that magnetic field annealing can be used for tuning of GMI characteristics of $(Fe_{0.5}Ni_{0.5})_{78}Nb_7B_{15}$ monolayer and bilayer ribbons. Bilayers provide higher magnetoimpedance ratio values as compared to their monolayer counterparts.

Acknowledgments

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