ELEVATED GIANT MAGNETO-IMPEDANCE IN AMORPHOUS METALLICAL CO-DASED ALLOYS

Leonid V. Poperenko, Dmytro Yu. Manko

Abstract:

This paper reviews results of an enhancement of giant magneto-impedance (GMI) in cobalt-rich amorphous glassy alloys. There are several ways of GMI increasing, namely: thermal, cryogenic and laser treatment. The results are explained via structural changes of ribbons surface and magnetio-optical properties. This phenomenon is interpreted via classical electromagnetic terms. The role of a conductive intermediate film in three-layer sandwich structures is also revealed. Such structure consisting of two cobalt-based ferromagnetic films and a conductive inner film of amorphous nickel shows significant increase of GMI ratio in comparison to a single layer.

GMI enhancement makes possible to create new types of high sensitive magnetic field sensors. The investigation of evaluation processes after the ribbons treatment substantiates to clear understanding the nature of GMI.

Keywords: *amorphous metallic alloys, giant magnetoimpedance, laser and thermal annealing, cryogenic treatment, three-layer structures.*

1. Introduction

Amorphous metallic alloys (AMA) possess improved magnetic properties compared with their crystalline analogues, which makes possible their application in devices of magneto-electronics [1]. Giant magneto-impedance effect in amorphous wires and amorphous metallic alloys ribbons has been investigated after its discovery since 1988. Its origin are associated with specificity of magnetic properties. In terms of a theory of electron transfer phenomena the giant magnetoimpedance is connected with spin-dependent scattering of the conduction electrons. This effect is peculiar to the low-coercivity AMA based on cobalt as well as multilayered films with consecutive ferromagnetic and nonmagnetic layers or granular ferromagnetic materials in the wire matrix. The films based on amorphous magnetic alloys are promising materials for mass production of cheap microelectronic sensors and sensing heads for reading information. There are several ways to increase the GMI ratio of amorphous metallic alloys namely: thermal and laser annealing [2][4] or joule heat flux *via* alternating current through the sample [5], as well as the influence of deformations waves [6] on the GMI. The influence of thermal and laser annealing, cryogenic treatment on physical parameters is presented in this work, as well as impact of intermediate layer of nickel in three layer structure (amorphous alloy/nickel/amorphous alloy). Achievement of maximal GMI value wasn't pursed in present work.

The GMI in the sandwich films has potential to be used in developing small sensitive magnetic heads for high density magnetic recording. Considering a real head the effect of in-plane sandwich width on GMI has to be studied. The problem is approached by finding the AC field distribution over the film width under the condition of a weak skin-effect [7].

1.1. Experimental technique

GMI effect has been investigated in magnetic fields up to 100 Oe and a frequency F of alternating current from 1 to 3000 kHz.

As-quenched (AC) AMA samples were obtained in the strips with width of 10-20 mm and thickness of 20-25 µm. Samples were annealed in vacuum (10^{-6} mm Hg) at temperatures of 350°C, 375°C and 400°C. Laser annealing procedure is described in work [5] namely: laser wavelength was 1064 nm, energy density order was equal to 2.5-3.5kW/cm² and applied external magnetic field was about 100 Oe. GMI was investigated in magnetic fields up to 100 Oe, and frequency alternating current that flew through the sample was varied from 10 to 220 kHz for AMA samples and from 1 to 3000 kHz for sandwiched AMA/Nickel/AMA structures. Magnetic field vector was oriented in the plane of the sample. GMI measurements were performed according to scheme which consists of the connected low-value resistor and investigated sample.

The GMI ratio ΔZ/Z was defined according to the expression:

$$\Delta U/U = (U_{H=0} - U_H)/U_{H=0} = \Delta Z/Z = (Z_{H=0} - Z_H)/Z_H$$

Where $Z_{H=0}$ and Z_H are impedances at $H = 0$ and the significance H of the magnetic field that corresponds to the largest value respectively. The compositions of the samples were determined by Auger spectroscopy. The three-layer sandwich structures were constructed using two AMA ribbons of the same kind with thicknesses 15 µm and a intermediate layer with width approximately 10 µm.

1.2. Results and discussion

Fig. 1 presents GMI ratio of ribbons of AMA $Co_{59}Fe_5Ni_{10}Si_{11}B_{15}$. The dependences show the impact of thermal and laser treatments on GMI ratio values which reach the maximum at a frequency of 100 kHz. These treatments don't change the maximum frequency localization. The relative value $\Delta U/U$ reaches the level of about 8-9%.

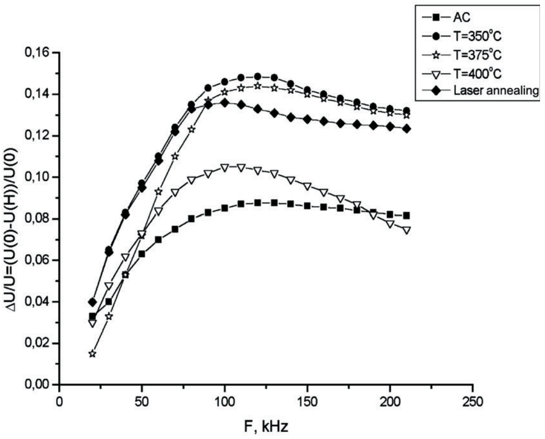

Fig. 1. GMI ratio in amorphous metallic ribbon of $Co_{59}Fe_5Ni_{10}Si_{11}B_{15}$ alloy.

The heat treatment of the sample at the temperature of 350°C during 10 minutes leads to the increase of GMI effect more than 1.8 times compared to the as-quenched (AC) ribbon. Higher temperature processing up to 400°C leads to the decrease of GMI ratio $\Delta Z/Z$ and its appropriate value is almost equal to that before the treatment. This phenomenon is obviously connected with the structural changes that were occurred in the ribbons during thermal processing. In that time laser annealing leads to the increase of GMI effect of about 1.7 times in AMA $Co_{59}Fe_5Ni_{10}Si_{11}B_{15}$ sample as well as an AMA $Co_{58}Fe_5Ni_{10}Si_{12}B_{16}$ one that is shown in Fig. 2. In the latter the laser annealing results in the enhancement of GMI ratio almost in two times (Fig. 1). The result of the influence of cryogenic treatment in liquid nitrogen on GMI ratio values of AMA $Co_{58}Fe_5Ni_{10}Si_{12}B_{16}$ ribbon is also shown in Fig. 2. Such behaviour implies that the exchange energy between large magnetic domains plays essential role at the low-frequency range below 1 MHz [8].

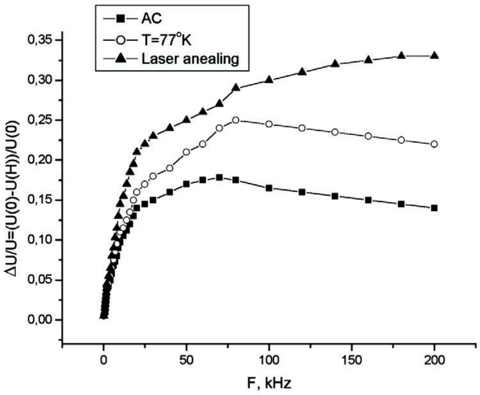

Fig. 2. GMI ratio in amorphous metallic ribbon of $Co_{58}Fe_5Ni_{10}Si_{12}B_{16}$ alloy.

The clusters, which arise as a result of thermal annealing, have no characteristic sizes and differ in shape [9]. Such surface structure occurs due to evolutionary processes of atoms diffusion towards microcrystalline centres inside amorphous matrix [9].

In the case of laser annealing, size of the clusters weakly dependends on the magnitude and location of microcrystalline centres that exist in the amorphous matrix [9]. It should be noticed, that during thermal annealing metal-metal and metal-metalloid phases emerge. Moreover such phases are moving towards sample surface.

A considerable enhancement of the GMI in three-layer structures can be achieved by separation between the conductive films and the magnetic films, which further decreases the DC resistance [10]. A very high sensitivity to an external field is typical for magnetoimpedance in soft ferromagnetic conductors with well-defined anisotropy. Thus, in CoFe(SiB) amorphous wires having almost zero magnetostriction and a circular domain structure is dominant [10]. Fig. 3 and Fig. 4 show the impact of a intermediate layer of nickel on a GMI ratio in the three-layer structures as compared to as-quenched one for appropriate AMA ribbons.

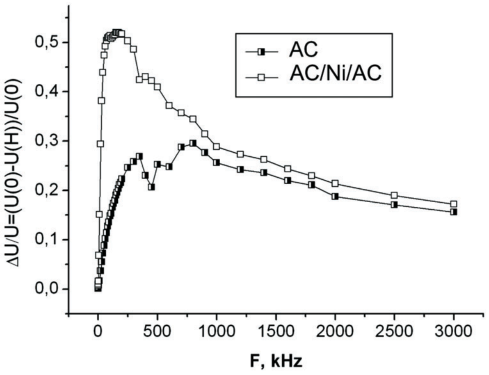

Fig. 3. GMI ratio in three layer system of $Co_{63}Fe_5Ni_5Si_{12}B_{15}/Ni/Co_{63}Fe_5Ni_5Si_{12}B_{15}$.

As it is seen, the intermediate layer presence leads to a dramatic increase of GMI ratio value nearly two times without physical treatment of the ribbon. Similar behaviour has been observed for another sample with AMA Co58Fe5Ni10Si12B16 ribbons being used (Fig. 4).

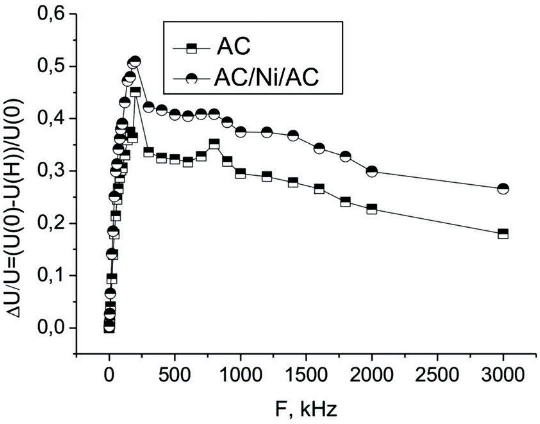

Fig. 4. GMI ratio in three layer system of $Co_{58}Fe_5Ni_{10}Si_{12}B_{16}/Ni/\ Co_{58}Fe_5Ni_{10}Si_{12}B_{16}$.

But in this case the enhancement of GMI ratio is much smaller. The enhancement of GMI ratio in such three-layer composite structure may be explained by consideration of their magnetic structures difference and the frequency dependence of their impedance Z. [11] The magnetic moment rotation becomes important under application of an external magnetic field and the value of such magnetic moment rotation is compared to existing intrinsic magnetic moment due to magnetic anisotropy field. Then the change of real and imaginary parts of the impedance contributes to GMI ratio. Moreover, the magnetic structure is varied after addition of some intermediate layer and the GMI effect behaviour is essentially changed and GMI ratio is just enhanced [11].

2. Conclusion

Summarizing, we can conclude that the influence of thermal, laser and cryogenic treatments on GMI ratio and physical characteristics in $Co_{59}Fe_5Ni_{10}Si_{11}B_{15}$ was established. Adding a nickel intermediate layer between to ribbons based on cobalt leads to significant enhancement of the GMI effect. The results can be explained by structural changes of amorphous ribbons surface and difference in magnetic structures and the frequency dependence of their impedance in case of three layer composites.

AUTHORS
Leonid V. Poperenko*, Dmytro Yu. Manko - Physics Department, Taras Shevchenko Kiev National University, Kiev, 03187, Ukraine. E-mails: plv@univ.kiev.ua, dmitriy.manko@univ.kiev.ua.
* Corresponding author

References

[1] Marin P., Hernando A., “Applications of amorphous and nanocrystalline magnetic materials”, *J. Magn. Magn. Mater.*, vol. 215-216, 2000, pp. 729-734.

[2] Panina L.V., Mohri K., Bushida K., Noda M., “Giant magneto-impedance and magneto-inductive effects in amorphous alloys”, *J. Appl. Phys.*, vol. 76, 1994, pp. 6198-6203.

[3] Knobel M., Pirota K.R., “Giant magnetoimpedance: Concepts and recent progress”, *J. Magn. Magn. Mater.*, vol. 242, 2002, pp. 33-40.

[4] Bulavin L.A., Kravets V.G., Vinnichenko K.L., Manko D.Yu., *„Optical Properties of Amorphous Co-Containing Alloys in the IR Region of the Spectrum and Their Magnetoresistive Characteristics”, Journal of Applied spectroscopy,* vol. 68, no. 5, 2001 pp. 599-604.

[5] Brunetti L., Tiberto P., Vinai F., Chiriac H., “High frequency giant magnetoimpedance in joule-heated Co-based amorphous ribbons and wires”, *Mater. Sci. Eng.*, vol. 304-306, 2000, pp. 961-964.

[6] Kurlyandskaya G.V., Barandiaran J.M., Vazquez M., Garcia D., Dmitrieva N.V., ”Influence of gemetrical parameters on the giant magnetoimpedance response in amorphous ribbons”, *J. Magn. Magn. Mater.*, vol. 215-216, 2000, pp. 740-742.

[7] Makhnovskiy D.P., Panina L.V., “Size effect on magneto-impedance in layered films”, *Sensors and Actuators*, vol. 81, 2000, pp. 91-94.

[8] Hye-S K., Heebok L., Kyeongsup K., Seong-Cho Y., Yong-Kook K., “Temperature dependence of the magneto-impedance effect in nanocrystalline $Fe_{84}Zr_7B_6Cu_1Al_2$ alloy”, *Journal of Alloys and Compounds*, vol 326, 2001, pp. 309-312.

[9] Kravets V.G., Petford-Long A.K., Portier X., Poperenko L.V., Kolesnik M., “The optical and magneto-optical properties and magnetoresistance of amorphous CoFeNiSiB alloys”, *J. Magn. Magn. Mater.*, vol. 217, 2000, pp. 129-138.

[10] Panina L.V., Mohri K., “Magneto-impedance in multilayer films”, *Sensors and Actuators*, vol. 81, 2000, pp. 71-77.

[11] Wang X.Z., Yuan W.Z., Li X.D., Ruan J.Z., Zhao Z.J., Yang J.X., Yang X.L., Sun Z., “Enhancement of giant magnetoimpedance in composite wire with insulator layer”, *J. Magn. Magn. Mater.*, vol. 308, 2007, pp. 269-272.