JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 10, No. 11, November 2008, p. 2913 - 2915

Hall effect and magnetoresistance of $Co_{68.25-x}Fe_{4.5}Si_{12.25}B_{15}Mo_x$ alloys

M. LOZOVAN[a*], H. CHIRIAC[a], M. NEAGU[b], S. MOHORIANU[a], V. DOBREA[a]
[a]*National Institute of R & D for Technical Physics, 47 Mangeron Blvd., 700050 Iasi 3, Romania*
[b]*"Al. I. Cuza" University, 11 Carol I Blvd. Iasi, 700506, Romania*

Results concerning the Hall resistivity, spontaneous Hall coefficient, longitudinal and transversal magnetoresistance and ferromagnetic anisotropic resistivity for as-cast and thermally treated $Co_{65.75}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_{2.5}$ amorphous ribbons are presented. The obtained results show a strong dependence of the electrical properties of the samples on the thermal treatment. In the nanocrystallized samples the value of ferromagnetic anisotropic resistivity ($+1.65\times10^{-4}$) is quite similar to that of the amorphous samples ($+1.17\times10^{-4}$). In the crystallized state the value of ferromagnetic anisotropic resistivity increases up to $+17.93\times10^{-4}$.

(Received September 1, 2008; accepted October 30, 2008)

Keywords: Magnetoresistance, Hall Effect; Ferromagnetic Anisotropic resistivity

1. Introduction

Nanocrystalline materials that display excellent soft magnetic properties have been a subject of increasing attention from scientific community, not only due to their potential use in technical applications, but also because they provide an excellent setting to study basic problems in nanostructures formation and magnetism [1-2]. Even at the initial stages of crystallization, the coexistence of different magnetic phases, and the possibility of modifying their size distribution and relative volume fraction through annealing, makes of these materials good environments to investigate interactions among magnetic particles, surface effects, transport properties and several new phenomena that emerged with the reduced dimensions of crystallites [3-4].

The $Co_{65.75}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_{2.5}$ amorphous ribbons are excellent soft magnetic materials having nearly zero magnetostriction and a very low magnetic anisotropy induced during the fabrication process. Structural changes are obtained in these materials if they are subjected to heat treatments and we can have crystalline or nanocrystalline phases after suitable thermal treatments at temperatures above or below the crystallization temperature. As a consequence the magnetic, magnetoelastic and galvanomagnetic properties of the materials change [4-6].

In this work we have studied the influence of the thermal treatments on the magnetoresistance, Hall Effect and ferromagnetic anisotropic resistivity (FAR) of $Co_{65.75}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_{2.5}$ amorphous ribbons prepared by the melt spinning technique. Measurements of Hall Effect and magnetoresistance are important sources of information for ferromagnetic materials, such as structural characterization, transport and magnetic properties. The amorphous state of the samples and the evolution of the nanocrystallization process after thermal treatments were examined by X-ray diffraction and differential thermal analysis (DTA). The obtained results provide some information about transport properties of the alloy in the examined states.

2. Theory

The Hall Effect and the transport properties of ferromagnetic metals are treated in most textbooks of ferromagnetism.

The curves of the Hall resistivity ρ_H vs. the magnetizing field are fitted by the formula (in e. m. u. as is generally used in literature for this subject):

$$\rho_H=E_y/j_x=hV_H/i_x=R_0B_z+R_s4\pi M_z \quad (1)$$

where j_x is the electric current density, E_y the electric field, V_y the Hall potential, h the sample thickness, i the current in the sample B_z is the magnetic induction, M_z is the magnetization.

The term R_0B_z has its origin in the Lorentz force acting on the electrons and R_0 is called the ordinary Hall constant that permits one to obtain the carrier charge density:

$$n=1/\,eR_0 \quad (2)$$

where e is the electron charge.

The term $4\pi M_zR_s$ is a contribution characteristic of the magnetic material and R_s is known as the extraordinary or the spontaneous Hall constant.

From an experimental point of view, the variation of ρ_H with the applied field H_a rather than with B is considered and Eq (1) can be rewritten as:

$$\rho_H=R_0[H_a+4\pi M(1-N)]+R_s4\pi M_z \quad (3)$$

where N is the demagnetizing factor. In our geometry N $\cong$ 1 and then Eq (3) becomes:

$$\rho_H = R_0 H_a + R_s 4\pi M_z \tag{4}$$

At saturation it follows that $H_a = 4\pi M_s$ and the Hall coefficients R_0 and R_s are determined directly from ρ_H or V_H curve, as indicated by Ref. [7].

Our results are analyzed by considering that, as indicated by Hurd [7] the slope of the curves below technical saturation is $R_s = (\partial\rho_H/\partial H)_{H=0}$ and at high fields is $R_0 = (\partial\rho_H/\partial H)_{H>4\pi M_s}$ because $R_s >> R_0$.

Usually, magnetoresistance is characterized by relative change of resistivity $\Delta\rho/\rho = [\rho(H)-\rho(0)]/\rho(0)$ in magnetic field, where $\rho(0)$ is the electrical resistivity measured in zero magnetic field. The curves $\Delta\rho_{||}/\rho = [\rho_{||}(H)-\rho(0)]/\rho(0)$ and $\Delta\rho_{\perp}/\rho = [\rho_{\perp}(H)-\rho(0)]/\rho(0)$ versus applied magnetic field are obtained experimentally by locating the ribbon sample with its long axis parallel and perpendicular respectively, to the magnetic field and with its plane parallel to the magnetic field (Figure 1). From these curves we can calculate the ferromagnetic anisotropic resistivity, defined as $(\rho_{||}-\rho_{\perp})/\rho(0)$, where $\rho_{||}$ and $\rho_{\perp}$ are the resistivity of the sample obtained in a saturating magnetic field.

The relative changes in electrical resistivity are positive when monitored as a function of the longitudinal magnetic field $\Delta\rho_{||}/\rho$ and negative when detected as a function of the transverse magnetic field $\Delta\rho_{\perp}/\rho$.

From these measurements informations on structural and compositional changes [2-6] and some magnetic properties could be obtained.

3. Experimental

The nearly zero magnetostrictive amorphous ribbons prepared by the melt spinning technique with nominal composition $Co_{65.75}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_{2.5}$ were tested in the as-cast state and after thermal treatments.

The crystalline ribbons were obtained by annealing the as-cast samples at 600°C, for 2 h. In order to obtain the nanostructured structures, the as-cast ribbons were furnace annealed at 475°C for 0.5 h.

During the thermal treatment the samples were placed in a special designed tube in argon atmosphere in order to avoid oxidation.

The Hall voltage measurements were carried-out by the Van der Pauw method, at room temperature, using external magnetic induction up to 2T, Cu contact pads with silver paint soldered wires and dc sample biasing currents between 5 and 60 mA [5]. A special shape of the samples was obtained by masking and etching.

Each Hall voltage value was the average of five measurements.

The longitudinal and transversal magneto-resistance measurements on the applied magnetic field (H) up to about 28 KA/m were performed at room temperature. The experimental results were obtained by a constant current power supply and a digital nanovoltmeter by means of a standard four-probe method in dc current [5].

4. Results and Discussions

Fig. 1 presents the dependence of the the Hall resistivity dependence on the applied magnetic field for the as-cast samples.

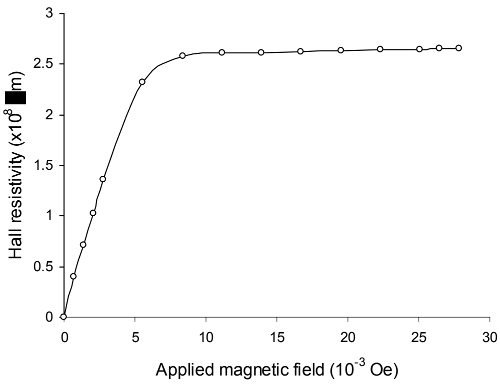

Fig.1. The Hall resistivity dependence on the applied magnetic field for the as-cast samples.

The value of the Hall resistivity increases continuously with applied magnetic field up to about 5.5 KOe and then it approaches saturation.

In Fig. 2 the dependence of the Hall resistivity on the applied magnetic field for the nanostructured and crystallized samples is presented.

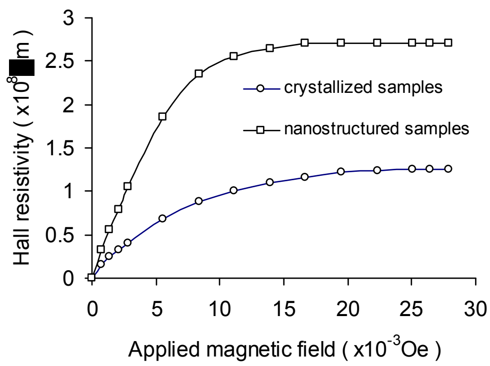

Fig. 2. The Hall resistivity dependence on the applied magnetic field for the nanostructured and crystallized samples.

The changes of the Hall resistivity in $Co_{66.25}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_2$ amorphous ribbons after thermal treatment are due to the structural relaxation that affects the magnetic stability, important changes of the saturation magnetostriction being also observed [2-4].

The magnetic stability of an amorphous alloy is related not only of the variation of induced magnetic anisotropy but also to the value of magnetostriction. In the as-cast state the saturation magnetostriction value is quite small (about 10^{-7}) and negative its value being sensitive to modification of amorphous microstructure, the heat treatments changing value of λ_s in a positive direction [2].

The magnetoresistance dependence on the applied magnetic field for $Co_{65.75}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_{2.5}$ samples in the amorphous, nanocrystalline and crystallized state respectively is presented in Figs. 3-4.

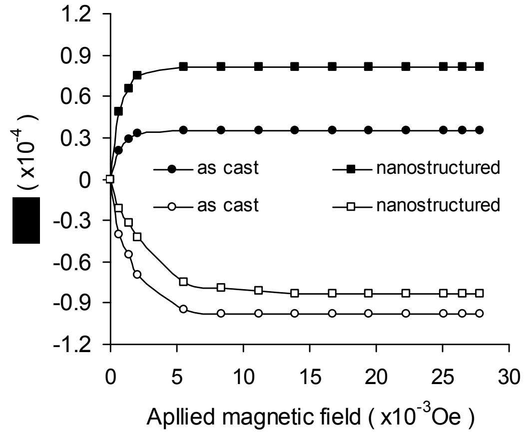

Fig. 3. The magnetoresistance dependence on the applied magnetic field for the nanostructured and as-cast samples.

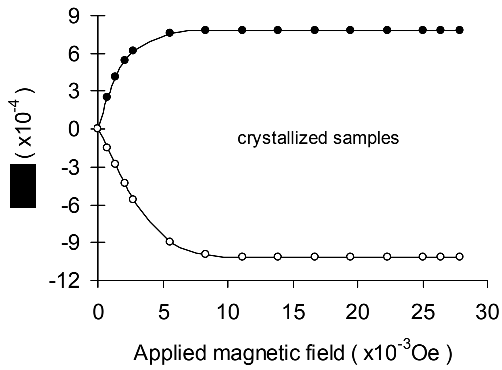

Fig. 4. The magnetoresistance dependence on the applied magnetic field for the crystallized samples.

It is interesting to observe important changes of ρ_H curve for $Co_{65.75}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_{2.5}$ samples in nanocrystallized and crystallized state.

After thermal treatment the asymmetry of the curves with respect to the field axis practically disappears because the induced magnetic anisotropy along the longitudinal axis of the ribbons is eliminated by thermal treatments and the axes of crystallites are randomly oriented.

The ferromagnetic anisotropic resistivity increases with temperature and time of the annealing process. In the nanocrystallized samples the value of FAR ($+1.65 \times 10^{-4}$) is quite similar to that of the amorphous samples ($+1.17 \times 10^{-4}$). In the crystallized state the value of FAR increase up to $+17.93 \times 10^{-4}$.

5. Conclusions

The Hall resistivity ρ_H and Hall coefficient R_S for $Co_{65.75}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_{2.5}$ amorphous ribbons as a function of external magnetic induction and current density annealing are presented.

The value of the Hall resistivity of the as-cast samples increases continuously with applied magnetic field up to about 5.5 KOe and then it approaches saturation. After thermally treatments, a remarkable change in the Hall resistivity is observed due to the structural relaxation and magnetic anisotropy induced by thermal treatment.

The ferromagnetic anisotropic resistivity increases with temperature and time of the annealing process. The obtained results provide some information about transport properties of the alloy in the examined states.

References

[1] P. Quintana, E. Amano, R. Valenzuela, J. T. S. Irvine, J. Appl. Phys. **75-10**, 6490 (1994).
[2] J. Gonzalez, N. Murillo, J. M. Blanco, P. Quintana, E. Amano, R. Valenzuela, IEEE Trans. Mag. **30**, 4812 (1994).
[3] H. K. Lachowicz, R. Zuberek, M. Kuzminski, A. Slawska-Waniewska, J. Magn. Magn. Mater. **196-197**, 151 (1999).
[4] J. Gonzalez, N. Murillo, J. M. Blanco, P. Quintana, E. Amano, R. Velenzuela, IEEE Trans. Magn. **30**, 4812 (1994).
[5] M. Lozovan, H. Chiriac, M. Neagu, J. Optoelectron. Adv. Mater. **9**(4), 848 (2007).
[6] S. Mohorianu, M. Lozovan, C. Baciu, J. Optoelectron. Adv. Mater. **9**(5), 1499 (2007).
[7] C. M. Hurd, Hall Effect in Metals and Alloys, Plenum Press, New York, 1972.

*Corresponding author: loz@phys-iasi.ro