Journal of Optoelectronics and Advanced Materials Vol. 2, No. 5, 2000, p. 671-675

Section 7: Non-crystalline materials

ON THE HALL EFFECT AND MAGNETORESISTANCE OF $Co_{66.25}Fe_{4.5}Si_{12.25}$ $B_{15}Mo_2$ AMORPHOUS AND CRYSTALLIZED RIBBONS

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In this paper we present results concerning the influence of the thermal treatments on the magnetoresistance, Hall effect and ferromagnetic anisotropic resistivity (FAR) of $Co_{66.25}Fe_{4.5}Si_{12.25}B_{15}Mo_2$ amorphous ribbons prepared by the melt spinning technique. 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 ($+1.78\times10^{-4}$) is quite similar to that of the amorphous samples ($+1.35\times10^{-4}$). In the crystallized state the value of ferromagnetic anisotropic resistivity increase up to $+18\times10^{-4}$.

Keywords: Hall effect, Magnetoresistance, Ferromagnetic anisoptropic 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 [1-3]. 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 [4-5].

The $Co_{66.25}Fe_{4.5}Si_{12.25}B_{15}Mo_2$ 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 nanocrystalline or crystalline phases after suitable thermal treatments at temperatures below or above 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 $Co_{66.25}Fe_{4.5}Si_{12.25}B_{15}Mo_2$ 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, differential thermal analysis (DTA) and differential scanning calorimetry (DSC).

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 Hall resistivity ρ_H vs. magnetizing field are fitted by the formula (in e. m. u. as generally used in specialized literature):

$$\rho_H=E_y/j_x=hV_H/i_x=R_0B_z+R_s4\pi M_z \tag{1}$$

where j_x is the electric current density, E_y is the electric field, V_H is the Hall potential, h is the sample thickness, i_x is the current in the sample B_z is the magnetic induction, M_z is the magnetization, R_0 is ordinary Hall constant, R_s is the extraordinary (or spontaneous) Hall constant, $4\pi M_zR_s$ is a characteristic of the magnetic material.

The term R_0B_z has its origin in the Lorentz force acting on the electrons. The carrier charge density can be determined with:

$$n=1/\ eR_0 \tag{2}$$

where e is the electron charge.

From experimental point of view the variation of ρ_H with the applied field H_a is more relevant than with B. In these case Eq (1) can be rewritten as:

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

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

$$\rho_H=R_0H_a+R_s4\pi M_z \tag{4}$$

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

The resistivity of ferromagnetic materials is sensitive to magnetic field presence and according to the magnetic domain theory it depends on the angle between magnetization and electric current in the sample. Usually, magnetoresistance is characterized by relative change of resistivity $\Delta\rho/\rho = [\rho(H)-\rho(0)]/\rho(0)$ in magnetic field. It is possible to evaluate the ferromagnetic anisotropic resistivity from $\Delta\rho_{||}/\rho$ and $\Delta\rho_{\perp}/\rho$. 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 to the magnetic field but with its plane parallel to the magnetic field. From these curves we calculated the ferromagnetic anisotropic resistivity [4], defined as $(\rho_{||}-\rho_{\perp})/\rho$, where $\rho_{||}$ and $\rho_{\perp}$ are the resistivities of the sample obtained in a saturating magnetic field aligned parallel and perpendicular to the current direction, respectively, and ρ is the electrical resistivity measured in zero 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 $\Delta\rho_{\perp}/\rho$.

3. Experimental

The nearly zero magnetostrictive amorphous ribbons prepared by the melt spinning technique with nominal composition $Co_{66.25}Fe_{4.5}Si_{12.25}B_{15}Mo_2$ 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 nanocrystalline 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 [8-10]. 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 magnetoresistance 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 [6].

4. Results and discussion

Fig. 1 presents the DSC curves recorded for the $Co_{68.25-x}Fe_{4.5}Si_{12.25}B_{15}Mo_x$ (x=0, 2).

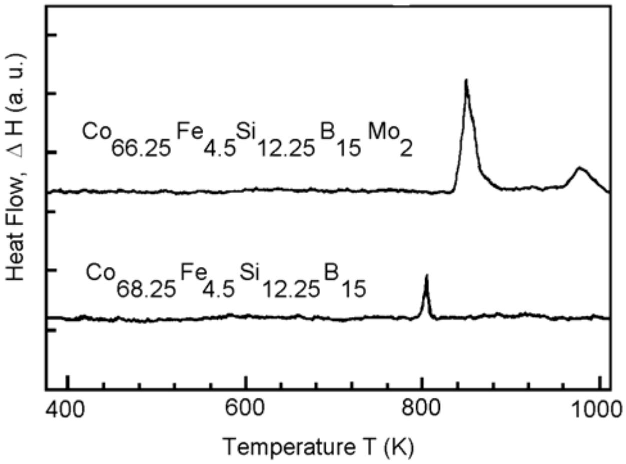

Fig. 1. The DSC curves for $Co_{68.25-x}Fe_{4.5}Si_{12.25}B_{15}Mo_x$ (x=0, 2) amorphous samples.

We observe that the substitution of Co by Mo in the CoFeSiB alloy shifts the onset of crystallization temperature towards higher temperatures. Two exothermic peaks are seen on the DSC curves for 2%Mo addition indicating a two-stage crystallization process.

Fig. 2 presents the dependence of the Hall resistivity 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. 3 the dependence of the Hall resistivity on the applied magnetic field for the nanostructured and crystallized samples is presented. 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 [3-4, 6].

The magnetic stability of an amorphous alloy is related not only to 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 the modification of the amorphous microstructure, the heat treatments changing the value of λ_s in a positive direction [3].

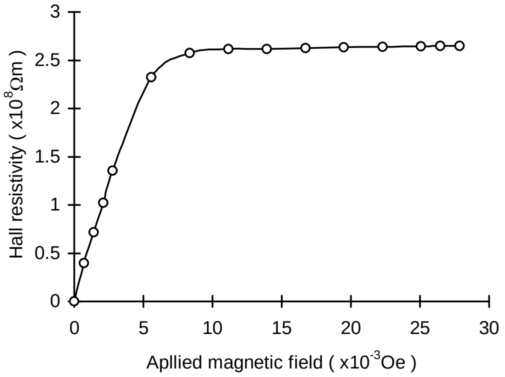

Fig. 2. The Hall resistivity dependence on the applied magnetic field for the as-cast samples.

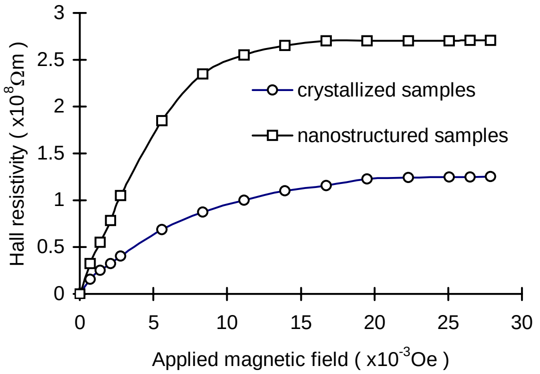

Fig. 3. The Hall resistivity dependence on the applied magnetic field for the nanostructured and crystallized samples.

The magnetoresistance dependence on the applied magnetic field for $Co_{66.25}Fe_{4.5}Si_{12.25}B_{15}Mo_2$ samples in the amorphous, nanocrystalline and crystallized state respectively is presented in Figs. 3-4. It is interesting to observe important changes of ρ_H curve for $Co_{66.25}Fe_{4.5}Si_{12.25}B_{15}Mo_2$ 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.

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The ferromagnetic anisotropic resistivity increases with temperature and time of the annealing process. In the nanocrystallized samples the value of FAR ($+1.78\text{x}10^{-4}$) is quite similar to that of the amorphous samples ($+1.35\ \text{x}10^{-4}$). In the crystallized state the value of FAR increases up to $+18\text{x}10^{-4}$.

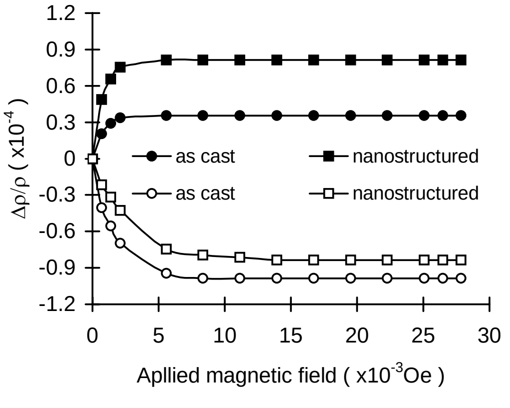

Fig. 4. The magnetoresistance dependence on the applied magnetic field for the nanostructured and as-cast samples.

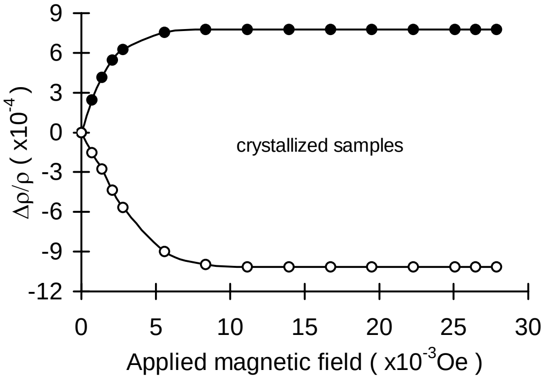

Fig. 5. The magnetoresistance dependence on the applied magnetic field for the crystallized samples.

4. Conclusions

In this paper we have studied the influence of the thermal treatments on the magnetoresistance, Hall effect and ferromagnetic anisotropic resistivity (FAR) of $Co_{66.25}Fe_{4.5}Si_{12.25}B_{15}Mo_2$ amorphous ribbons.

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.

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