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On the Hall effect in low magnetostrictive $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous ribbons

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Results concerning the Hall voltage U_H and spontaneous Hall coefficient R_s dependence on the external magnetic induction and heat treatment conditions for $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous ribbons tested in the as-cast state and after stress current annealing are presented. The saturation magnetostriction λ_s of $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ ribbons change its value and sign from about -1.1×10^{-7} to about $+2.95 \times 10^{-7}$ when stress current density annealing increase up to 200×10^6 A/m^2. An n-type conductivity was observed for this kind of material. The obtained results show a strong dependence of the electrical properties of the samples on the current density annealing.

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1. Introduction

Hall effect is a good method to study magnetic properties of materials. Measurements of Hall effect and magnetoresistance are important sources of informations of ferromagnetic materials, such as transport, characterization, and magnetic properties.

The $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ 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 amorphous materials by heat treatments and consequently the magnetic, magnetoelastic and electric properties of the material change [1-7].

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.

This paper presents some results concerning the galvanomagnetic properties of $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous ribbons prepared by the melt spinning technique. The amorphous ribbons were tested in the as-cast state and after stress current annealing. The obtained results provide some information about the structural characterization and transport properties of the alloy in the examined states.

2. Theory

The three basic galvanomagnetic effects of ferromagnetic metals are presented in Fig. 1.

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

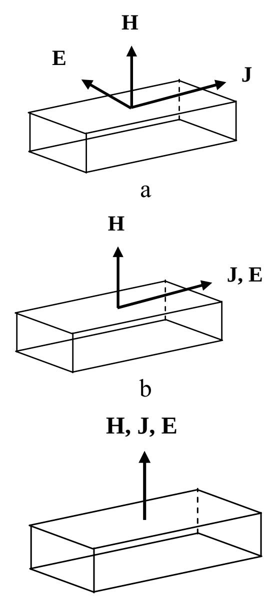

Fig. 1. The basic galvanomagnetic effects. H-magnetic field, J-current, E-electric field. a-Hall Effect, b-transverse magnetoresistance effect, c-longitudinal magnetoresistance effect.

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):

$$\rho_H = E_y/j_x = hV_H/i_x = R_0 B_z + R_s 4\pi M_z \qquad (1)$$

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:

$$n=1/ eR_0 \qquad (2)$$

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:

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

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

$$\rho_H=R_0H_a+R_s4\pi M_z \qquad (4)$$

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. [8].

Our results are analyzed by considering that, as indicated by Hurd [8] 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 (Fig. 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 resistivities of the sample obtained in a saturating magnetic field.

From these measurements informations on structural and compositional changes [2,4-6] and some magnetic properties could be obtained.

3. Experimental

The nearly zero magnetostrictive amorphous ribbons prepared by the melt spinning technique with nominal compositions $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ were tested in the as-cast state and after heat treatment.

The heat treatments for transport properties of the studied samples were made using the stress current annealing technique, the increase in temperature being obtained by the Joule effect. An electric current up to about 30×10^6 A/m^2 for 30 minutes annealing time passes through the amorphous ribbons under 75 MPa tensile stress. During the stress current annealing the samples were placed in a special designed tube in argon atmosphere in order to avoid oxidation.

The Hall voltage and the voltage for magnetoresistance are measured using a KEITHLEY nanovoltmeter. The sample is connected to the DC constant current source which allows us to set biasing current in the sample in ranges from 10 μA up to 150 mA. The Hall voltage measurements were carried-out by five point contact method [9] using external magnetic induction values up to 2T, Cu contact pads with silver paint soldered wires and dc sample biasing currents between 5 and 60 mA [1, 3]. A special shape of the samples was received by masking and etching [10].

Five point contact method for elimination of zero field asymmetry external magnetic induction were used. The current contact I_1 and I_2 are placed parallel to the sample axis. For monitoring of Hall voltage three potential contacts U_1, U_{21}, U_{22} are connected to the sample as indicated in Fig. 2.

Each Hall voltage value was the average of five measurements. The Hall voltage measurements were performed at room temperature.

The voltage between contacts U_{21} and U_{22} is used for resistivity measurements. A potentiometer over to 50 kΩ connected to these contacts allows to set the zero initial Hall voltage between virtual contact and U_1 contact.

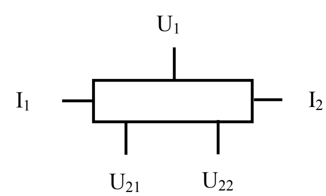

Fig. 2. The ribbon sample with current (I_1, I_2) and voltage (U_1, U_{21}, U_{22}) contacts.

The source of magnetic field is a Weiss type electromagnet with iron core connected to a power supply of 10A. Maximal value of magnetic induction dependent on the air gap and typically is 2.1T.

The saturation magnetostriction was determined using small angle magnetization rotation technique [11-13].

4. Results and discussion

Fig. 3 presents the dependence of the Hall voltage on the external magnetic induction applied during measurements for $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous ribbons tested in the as-cast state for three sample biasing current values (20, 40, 60 mA). All examined samples exhibit an n-type conductivity. The absolute value of the Hall voltage increases continuously with magnetic induction up to about 0.85 T and then it approaches to the saturation. The value of the Hall voltage is strongly dependent on the sample biasing current, increasing when the current value increases. As it can be seen from the Fig. 3, the reduction of the initial slope of curves is in agreement with sample biasing currents reduction.

Fig. 4 presents the dependence of the Hall voltage on the current density annealing for 30 minutes under 75 MPa, at 0.65 T external magnetic induction.

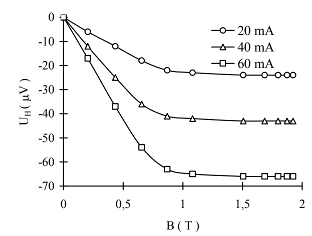

Fig. 3. The Hall voltage dependence on the external magnetic induction for amorphous ribbons in the as-cast state.

For current density annealing up to about 17×10^6 A/ m^2 a decrease of the Hall voltage is observed. For density current between $(17 - 22) \times 10^6$ A/ m^2 the Hall voltage linearly increases and above 22×10^6 A/m^2 exhibits a strong decrease in absolute value.

In Fig. 5 the dependence of the Hall constant R_s on the current density annealing is presented.

The dependence of the saturation magnetostriction at zero applied stress, $\lambda_s(0)_{max}$, on the current density annealing for 10 minutes under 477 MPa for $Co_{68.15}Fe_{4.35}Si_{12.5}B_{15}$ amorphous ribbons is presented in Fig. 6.

The changes of the Hall voltage and R_s coefficient in $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous ribbons after stress current annealing are due to the structural relaxation that affects the magnetic stability, important changes of the saturation magnetostriction being also observed.

When an amorphous material is subjected to external stress, a magnetoelastic anisotropy is induced which will be added to the initial anisotropy due to residual internal stresses. The resulting anisotropy will determine the magnetic and magnetoelastic behavior of the sample.

For the studied samples the saturation magnetostriction λ_s change its value and sign from about -1.1×10^{-7} to about $+2.95\times10^{-7}$ when current density increase up to 200×10^6 A/m^2.

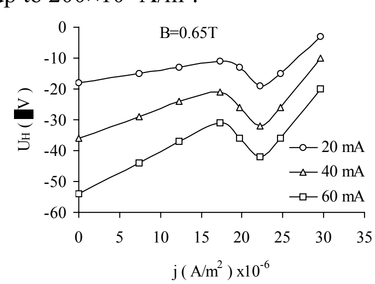

Fig. 4. The Hall voltage dependence on the current-density annealing for 20, 40 and 60 mA dc sample biasing current and 0.65 T external magnetic induction.

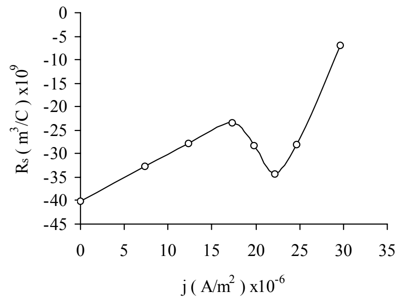

Fig. 5. The dependence of the Hall constant R_s on the current density annealing.

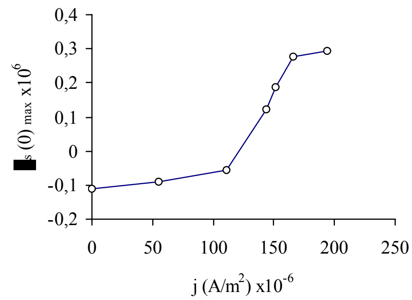

Fig. 6. The dependence of the saturation magnetostriction at zero applied stress, $\lambda_s(0)_{max}$, on the current density during stress current annealing

5. Conclusions

The Hall voltage U_H and Hall coefficient R_s for $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous ribbons as a function of external magnetic induction and current density annealing are presented.

All examined samples exhibit an n-type conductivity. After stress current annealing, a remarkable change in the Hall voltage is observed due to the structural relaxation and magnetic anisotropy induced by stress current annealing.

For the studied samples the saturation magnetostriction λ_s change its value and sign from about -1.1×10^{-7} to about $+2.95\times10^{-7}$ when current density increase up to 200×10^6 A/m^2.

The obtained results show that the $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous ribbons exhibit very good magnetostrictive properties for technological applications where a low positive, negative or zero magnetostriction is required.

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