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MAGNETIC CHARACTERISATION OF WIRES COVERED BY Fe-Co-Cu-Nb-Si-B GLASS

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Results on the effect of Fe substitution with different percents of Co on the magnetic behavior of $Fe_{73.5-x}Co_xCu_1Nb_3Si_{7.5}B_{15}$ as-cast and thermally treated glass-covered wires are reported. The Co addition to the FeCuNbSiB alloy influences the magnetic properties (H^*, M^*/M_s, and H_c) of samples both in the as-cast state and after annealing.

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1. Introduction

Nanocrystalline phases produced by crystallization of amorphous FeCuNbSiB alloys are known to show interesting physical properties. Nanocrystalline structures offer a new opportunity for tailoring the magnetic properties of soft magnetic materials. The most prominent example is the nanocrystalline $Fe_{73.5}Cu_1Nb_3Si_{7.5}B_{15}$ alloy obtained by devitrification of the amorphous precursor [1]. This alloy reveals a homogeneous ultrafine grain structure of bcc α-FeSi grains of 10-20 nm in diameter and random orientation embedded in a still amorphous matrix. Due to the small size of grains the local magnetocrystalline anisotropy is randomly averaged out by exchange interactions so that there is only a small anisotropy effect on the magnetization process. The structural phases that are formed lead to low saturation magnetostriction which minimize the magnetoelastic anisotropies. The excellent soft magnetic properties of the nanocrystalline materials such as high saturation induction comparable to that of iron-based metallic glasses, high permeability comparable to that of cobalt-based metallic glasses, very small coercive field, and low saturation magnetostriction are due to the formation of nanometer-size grains, which determines a significant decrease of the magnetic anisotropy by averaging out the magnetocrystalline anisotropy and a decrease of the saturation magnetostriction by an order of magnitude after crystallization [2].

Many results were reported especially for alloys in the ribbon shape, the studies being focused on the effect of the annealing conditions (temperature and time) on the magnetic properties of amorphous ribbons. Only few were concentrated on the glass-covered amorphous wires [3,4] and on the effect of additions on wires' magnetic behavior [5].

2. Experimental

We prepared the amorphous glass covered wires having the composition $Fe_{73.5-x}Co_xCu_1Nb_3Si_{13.5}B_9$ (x = 0, 3.6, 7.3, 14.7, 50, 65, 70, 73.5), about 20 μm in diameter and 15 μm thickness of the glass cover by the glass coated melt spinning technique. The samples were isothermally annealed for one hour in an electric furnace in Ar atmosphere at temperatures between 450 and 600°C. Transient temperature effects were minimised by rapidly inserting and extracting the samples from the special designed furnace. The amorphous and the nanocrystalline phase formation were checked by X-ray diffraction, DTA and thermomagnetic measurements. The magnetic measurements were performed by a fluxmetric method at 50 Hz and a maximum applied field of 25000 A/m [6].

3. Results and discussion

In the amorphous state, FeCuNbSiB amorphous glass covered wires behave like any positive magnetostrictive amorphous glass covered wires; they present Large Barkhausen effect at low fields due to the axially magnetized inner core, arising from the coupling between the positive magnetostriction ($\lambda_s = +20 \times 10^{-6}$) and internal stresses induced during preparation. The value of reduced magnetization, M^*/M_s, is close to 0.85. Fig. 1 illustrates the dependence of the switching field, H^*, and reduced magnetization, M^*/M_s, on the annealing temperature. One observes that both quantities decrease with the increase in the annealing temperature up to 550°C. For temperatures of annealing higher than 550°C the LBE vanishes. For temperatures up to 450°C the decrease of H^* and M^*/M_s is due to the stress relief that occurs during annealing. After 550°C, LBE vanishes due to the appearance of the nanocrystalline phase [3], i.e. since the positive magnetostriction of the residual amorphous matrix and the negative one of α-FeSi nanocrystals are averaged out, resulting in a nearly zero macroscopic magnetostriction, the wires behaving like the amorphous Co-based zero-magnetostrictive wires.

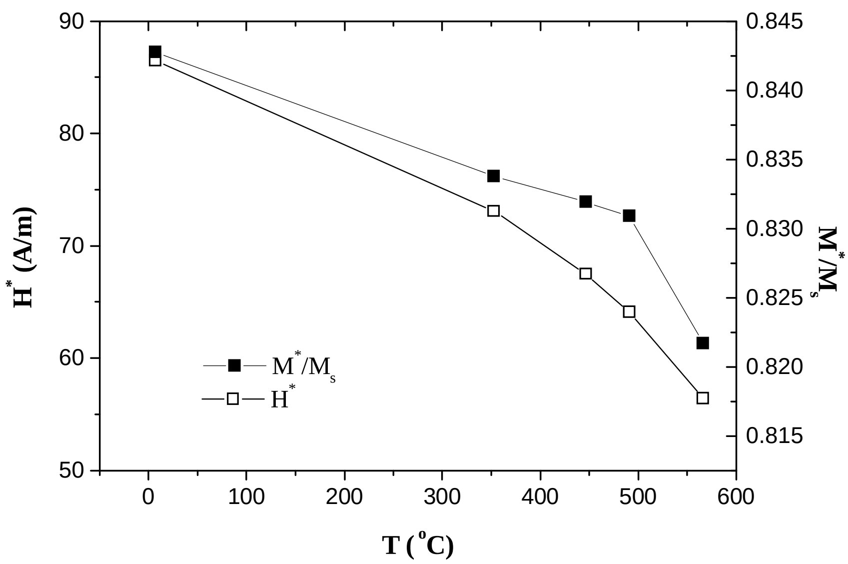

Fig. 1. Dependence of switching field, H^*, and reduced magnetization, M^*/M_s, on the annealing temperature for $Fe_{73,5}Cu_1Nb_3Si_{13.5}B_9$ glass-covered wires.

A similar behavior was observed for the coercive force. H_c decreases as the temperature increases up to 550°C, when a minimum value is reached. The minimum H_c corresponds to the nanocrystalline phase formation, which is characterized by good soft magnetic properties, especially by low coercivity. The decrease of H_c is determined by stress relief for annealing temperatures smaller than 550°C, while for temperatures higher than 550°C, a major contribution is also given by the decrease of the magnetoelastic anisotropy due to the reduction of λ_s.

Fig. 2 illustrates the switching field dependence on the Co content for the as-cast and annealed samples. The replacement of small amounts of Fe with Co determines an increase in H^* for the amorphous samples having up to 7.3 at % Co. The increase in the Co content up to 65 at% results in the decrease of H^*. For 65 at% Co the observed hysterezis loop becomes asymmetric. Further increase in Co content lead to the suppression of the switching field.

For the samples annealed at temperatures up to 500°C a slight improvement in the soft magnetic properties was observed as a result of the internal stress relaxation and decrease of λ_s.

The thermal treatments performed at 550°C lead to a small decrease of H^* for samples having up to 3.5 at % Co followed by an important increase for 7.3 at% Co and then to a decrease for the samples having 50 at% Co. For the samples having more than 65 at% Co the samples does not present the bistable behavior.

We noticed a similar behavior for the dependence of H_c on Co concentration and temperature up to the values at which the switching field still manifests.

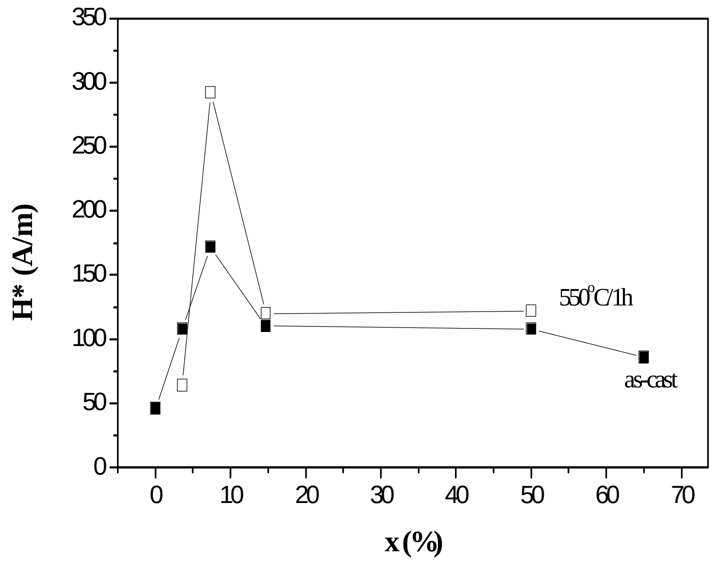

Fig. 2. The dependence of the switching field, H*, on the Co content for as-cast and annealed at 550°C $Fe_{73.5-x}Co_xCu_1Nb_3Si_{13.5}B_9$ (x = 0, 3.6, 7.3, 14.7, 50, 65, 70, 73.5) glass-covered wires.

The coercive field of the annealed samples having more than 50 at% Co increases up to about 8000 A/m. At this stage of annealing the size of the crystallites in the samples having more than 50 at% Co is around 200 nm, about 10 times larger than the size of the crystallites formed at the same temperature of annealing for the samples having up to 14% Co.

The changes induced in the magnetic properties of the as-cast samples, by replacing the Fe with Co, could be ascribed to the changes in the magnetostriction constant which is responsible for the modification of the domain structure from the one specific for the positive magnetostrictive wires in the case of wires having up to 65 at% Co, to the domain structure specific for the zero-magnetostrictive wires, in the case of wires having higher Co [6].

The dependence of the magnetic properties as a function of temperature for the samples having different Co content could be explained by taking into account the structural modifications induced by annealing. Thus, for the alloy without Co the disappearance of the coercive field is related to the formation of the α-FeSi grains. For the sample having low Co content an α-Fe(Si, Co) phase is formed, this phase being responsible for the increase in H* and also for the observed increase in H_c. The drastic depreciation in the soft magnetic properties for the samples with high Co content could be ascribed to the precipitation of β-Co phases [7].

4. Conclusions

In conclusion, we have analyzed the influence of Fe replacement with Co and of the crystallization process on the magnetic properties of $Fe_{73.5-x}Co_xCu_1Nb_3Si_{7.5}B_{15}$ (x=0, 3.6, 7.3, 14.7, 50, 65, 70, 73.5) glass-covered amorphous wires. The magnetic properties of samples (H*, M*/Ms, and

H_c) are modified both by Co addition and thermal treatments, giving the possibility to tailor them in function of required applications.

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