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Effect of dc-Joule-heating thermal processing on magnetoimpedance of $Fe_{72}Al_5Ga_2P_{11}C_6B_4$ amorphous alloy

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Abstract

The effect of multistep dc-Joule-heating thermal processing on magnetoimpedance (MI) of $Fe_{72}Al_5Ga_2P_{11}C_6B_4$ ribbons is presented. After material optimization significant increase of MI response up to value $\Delta Z/Z \approx 55\%$ as well as sensitivity of about 6%/kA/m (for $H \leqslant 3$–4 kA/m), were recorded in still amorphous samples at driving frequencies 2–3 MHz. On-line and post-annealing electrical resistivity together with Mössbauer spectra analysis and frequency dependence of the penetration depth were used for characterization of MI improvement.

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Keywords: Magnetoimpedance; Joule heating; Amorphous ribbons; Soft magnetic materials; Mössbauer spectroscopy

1. Introduction

One of the most interesting phenomena observed in soft magnetic amorphous ribbons (or wires or thin films) is magnetoimpedance (MI) effect. The influence of an external dc magnetic field (H) on a MI element is manifested by significant changes in the impedance. In classical skin-effect explanation, materials with high-magnetic permeability (μ) and low electrical resistivity (ρ), at relatively high frequencies (f) have penetration depth (δ_m) lower than the ribbon thickness (d):

$$\delta_m = \sqrt{\frac{\rho}{\pi \mu f}} \leqslant d \qquad (1)$$

and therefore δ_m have influence on MI response.

Penetration depth can be tailored by the changes of physical properties (μ and ρ) applying different experimental techniques: field-annealing, current annealing (CA), stress annealing, as well as combinations of these techniques. CA is especially interesting due to the simultaneous effects of Joule heating and appearance of a transverse magnetic field induced by the current flow. These features of CA treatments make them attractive for the optimization of magnetic microstructure, i.e. for improvement of transverse magnetic anisotropy (μ_T) that is crucial to obtain large MI effect in ribbons [1]. The development of the Fe-based bulk metallic glasses (BMG) in the middle of nineties [2] has attracted a great interest in these materials not only due to empirical rules for the stabilization supercooled liquid but also owing to the perspective applications of these alloys in various technical purposes. Moreover, Fe–(Al, Ga)–(P, C, B, Si) and Fe–(Cr, Mo)–(P, C, B, Ge) are among the softest Fe-based amorphous and nanocrystalline magnetic materials known [3,4]. Their excellent magnetic properties have been explained in terms of the much higher packing density of BMG [5] that leading to the lower pinning force due to an elastic stress in comparison with conventional amorphous alloys.

In our previous works it has been displayed that Fe–Al–Ga–P–C–B alloys exhibit low coercivity [6], i.e. high permeability, necessary for giant MI effect. In order to

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