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Giant Magnetoimpedance effect and magnetization in amorphous alloys system of FeCoNbBSiCu

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In this paper, it is reported the Giant Magnetoimpedance (GMI) effect and the saturation magnetization of amorphous alloys system of $(Fe_{72-x}Co_x)Nb_6B_{10}Si_{11}Cu_1$ ($x = 35$ and 40 at. % Co) obtained by the melt spinning technique. It was investigated the MI effect at different frequencies with a dc applied magnetic field. Low maximum MI ratios were found for the studied alloys and a higher value of 10.3 % was obtained for the alloy of composition $x = 35$. It was observed that the MI response depends considerably upon the particular magnetic structure of the sample and the used frequency range. The hysteresis curves showed the magnetic softness of the samples and a higher saturation magnetization value was obtained for the alloy of composition $x = 35$.

Keywords: Amorphous magnetic materials; magnetoimpedance; magnetization.

En este artículo se reporta el efecto de Magnetoimpedancia (MI) y la magnetización de saturación de aleaciones amorfas del sistema $(Fe_{72-x}Co_x)Nb_6B_{10}Si_{11}Cu_1$ ($x = 35$ y 40 at. % de Co) obtenidas por la técnica de la rueda fría. Se investigó el efecto de MI a diferentes frecuencias con un campo magnético aplicado dc. Se encontraron valores bajos en la máxima razón de cambio en la MI para las aleaciones estudiadas, obteniéndose un valor mayor de 10.3 % para la aleación de composición $x = 35$. Se observó que la respuesta en la MI depende considerablemente de la estructura magnética de la muestra y del rango de frecuencia utilizado. Las curvas de histéresis mostraron el comportamiento magnético blando de las muestras y se obtuvo un valor mayor de magnetización de saturación para la aleación de composición $x = 35$.

Descriptores: Materiales magnéticos amorfos; magnetoimpedancia; magnetización.

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1. Introduction

Amorphous magnetic alloys are commonly produced by the melt spinning technique. The most important applications of these materials are based on soft magnetic properties (high magnetic permeability, low coercitive field and high saturation magnetization), which make these alloys be applied in magnetic sensors, magnetic recording heads, etc. [1]. In 1992, it was discovered the Giant Magnetoimpedance (GMI) phenomenon [1] in the amorphous magnetic materials. This phenomenon consists of large changes in impedance when the material is subjected to an external dc magnetic field. The GMI was investigated for the first time in FeCoSiB amorphous ribbons based on their possible applications in the manufacture of magnetic sensors [2]. Subsequently, it was investigated the effect of GMI in $Co_{70.4}Fe_{4.6}Si_{15}B_{10}$ amorphous ribbons [3] and $Co_{68.1}Fe_{4.4}Si_{12.5}B_{15}$ amorphous wires [4]. Since then, there have been numerous studies on the GMI effect in a wide variety of soft magnetic alloys such as FINEMET (FeNbBSiCu) and Co-based alloys. However, it has been reported little in the literature about this effect in (FeCo)NbBSiCu alloys [5].

The GMI phenomenon has attracted much attention because of its tremendous prospects in technological applications, especially in the design of magnetic sensors [2], but also it is a very useful tool in the basic magnetic characterization of soft magnetic materials [6]. This article presents the obtained results of the Giant Magnetoimpedance (GMI) effect and the saturation magnetization of amorphous alloys system of $(Fe_{72-x}Co_x)$ $Nb_6B_{10}Si_{11}Cu_1$, for x = 35 and 40 at. % Co.

2. Experimental procedure

Measurements of the Giant Magnetoimpedance effect of the samples were performed on an electric impedance analyzer equipment, using a frequency range of the current applied from 0.5 to 20 MHz and with a magnetic field applied parallel to the sample, in a range from -80 to 80 Oe. Amorphous ribbons of 7 cm long and 1.1 mm wide were used for the GMI measurements. For measurements of saturation magnetization, magnetic hysteresis curves were recorded using a magnetic field of 1.1 T in a Vibrating Sample Magnetometer (VSM). GMI and saturation magnetization measurements were performed at room temperature.

3. Results and discussion

In Fig. 1 is presented the results of the GMI effect for the alloy of composition $Fe_{37}Co_{35}Nb_6B_{10}Si_{11}Cu_1$.

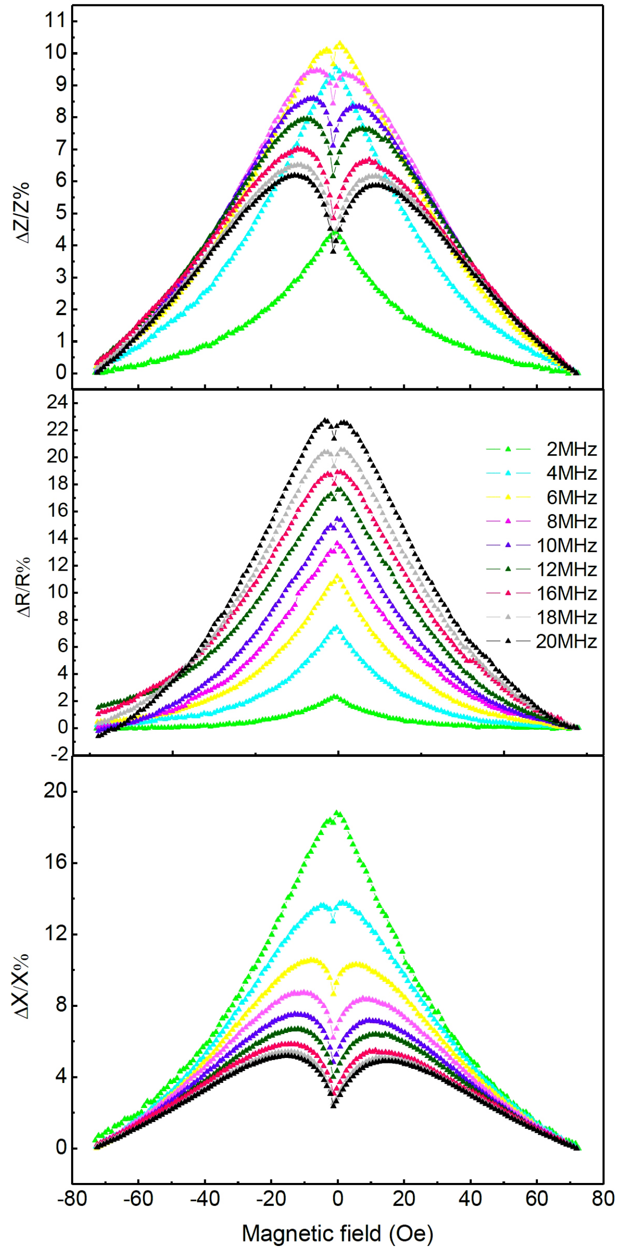

FIGURE 1. Change ratio in the total impedance ΔZ/Z, the resistance ΔR/R and in the reactance ΔX/X, as a function of the magnetic field for the amorphous alloy composition x = 35 at different frequencies.

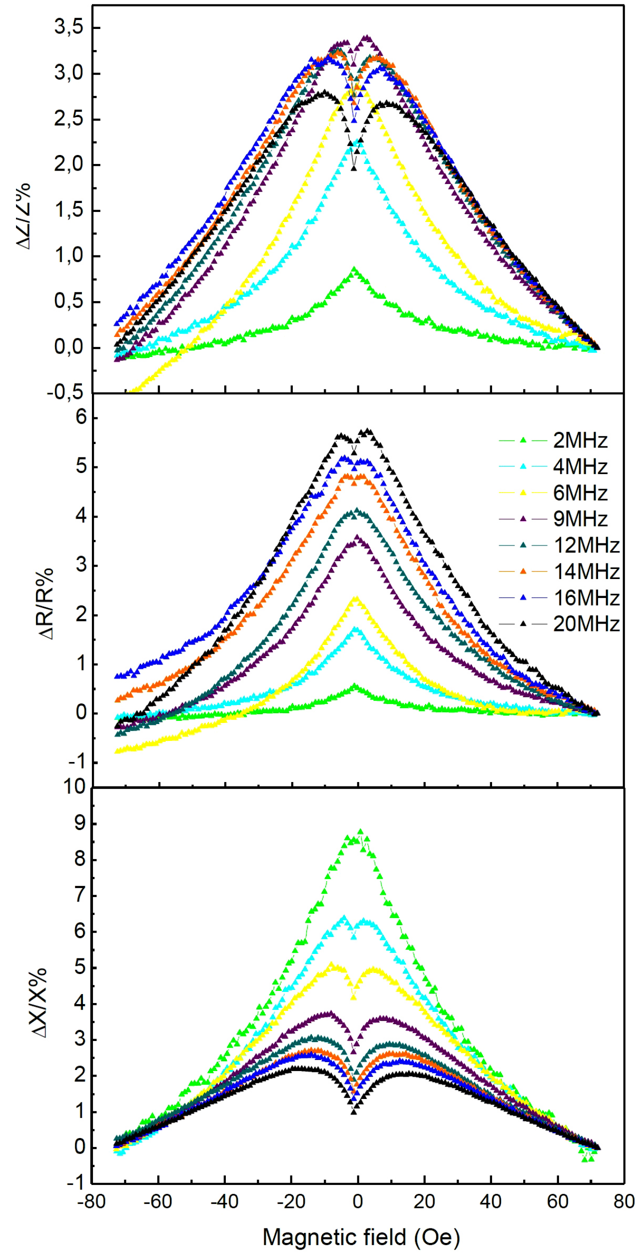

FIGURE 2. Change ratio in the total impedance ΔZ/Z, the resistance ΔR/R and in the reactance ΔX/X, as a function of the magnetic field for the amorphous alloy composition x = 40 at different frequencies.

It is shown the dependence of the change ratio in total impedance, resistance and reactance in the frequency range of 0.5 to 20 MHz. It is obtained a maximum change ratio of 10.3 % for the total impedance, 22.7 % for the resistance and 21.6 % for the reactance. The GMI spectra obtained in a frequency range 1 to 20 MHz for the alloy composition $Fe_{32}Co_{40}Nb_6B_{11}Si_{10}Cu_1$ are shown in Fig. 2. It is obtained a maximum change ratio of 3.4 % for the total impedance, 5.9 % for the resistance and 9.4 % for the reactance.

For the alloy of composition x = 35, the maximum change MI ratio, $(\Delta Z/Z)_{max}$, is reached at a frequency of 6 MHz, which is the relaxation frequency, f_x, for this alloy. For the alloy of composition x = 40, f_x is 9 MHz.

For both alloys, the spectra of GMI present a single and double peak behavior. The double peak behavior is due to the rotation of the magnetization produced by the ac current across the ribbon, as it is reported in Refs. 7 and 8.

The Table I shows the obtained results of the GMI spectra for the alloys of study.

The difference between the values of MI for each simple can be due to the modification of the magnetic structure of the material [8], when Fe atoms are substituted by Co atoms,

TABLE I. Maximum change ratio in the impedance, $(\Delta Z/Z)_{max}$, in the resistance, $(\Delta R/R)_{max}$, in the reactance, $(\Delta X/X)_{max}$, and relaxation frequency, f_x, for the amorphous alloys system of $Fe_{72-x}Co_xNb_6B_{11}Si_{10}Cu_1$.

Composition (at. % Co)	$(\Delta Z/Z)_{max}$ (%)	$(\Delta R/R)_{max}$ (%)	$(\Delta X/X)_{max}$ (%)	f_x (MHz)
x = 35	10.3	22.7	21.7	6
x = 40	3.4	5.9	9.4	9

TABLE II. Saturation magnetization (M_S) and coercitive field (H_C) for the amorphous alloys $x = 35$ and $x = 40$.

Composition	M_S(emu/g)	H_C(Oe)
x = 35	71	5.4
x = 40	83	2.9

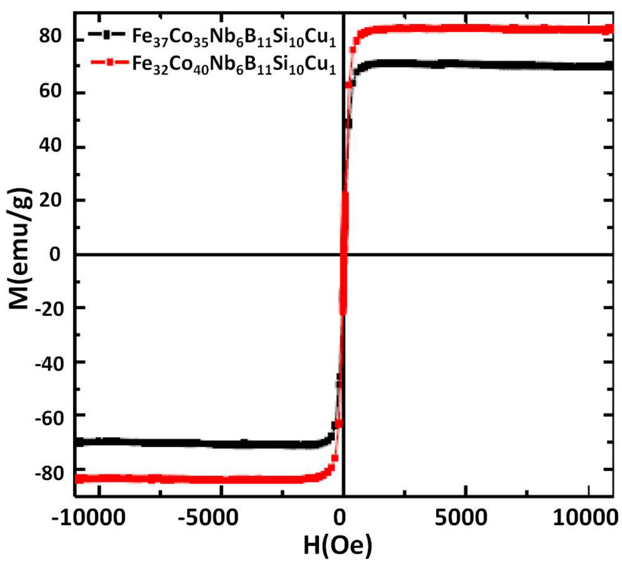

FIGURE 3. Hysteresis curves for the amorphous alloys x = 35 and 40 at room temperature and an applied magnetic field of 1.1 T.

affecting the magnetic permeability and consequently, the impedance of the material. By the other hand, as it can see from the Table I, the values of the maximum change ratio in the magnetoimpedance for the alloys are very small in comparison with the obtained value ($\sim$ 30 %) for the amorphous ribbon of composition $Co_{64}Fe_{21}B_{11}$ reported by Coisson *et al.*, in Ref. 9. Even, it has been reported changes in the magnetoimpedance up to 250 % for amorphous wires of composition $(Fe_6Co_{94})_{72.5}Si_{12.5}B_{15}$ [10] and about 50% for amorphous microwires of composition $Fe_{4.5}Co_{80}Si_{10}B_{1.5}Nb_4$ [8].

The increasing in the change MI ratios up to the relaxation frequency is due to the electromagnetic skin effect, as it is reported by Rahman *et al.*, [11].

The hysteresis curves of the alloys x = 35 and 40 are shown in Fig. 3. It is observed a high saturation magnetization and a low coercitive field; these features identify the soft magnetic behavior of both alloys. From the hysteresis curves, it was calculated the saturation magnetization (M_s) and the coercive magnetic field (H_c) values for the alloys of study, as it is shown in Table II.

It is observed that the saturation magnetization increases when Co content is increased; it was obtained a value of 71 emu/g (0.70 T) for the sample x = 35 and a value of 83 emu/g (0.82 T) for the sample x = 40. These results are according to the reported values by Zbroszczyk *et al*, [12] for alloys of the system $Fe_{73.5-x}Co_xSi_{13.5}B_9Nb_3Cu_1$ when x increases from 0 to 0.7 at. % Co. The addition of Co in these alloys increases the saturation magnetization about 3 % and the values of the coercive magnetic field decrease. Similar results were reported in literature [13] for FINEMET and NANOPERM alloys systems added with Co, in which the saturation magnetization increases at room temperature.

By the other hand, the M_S value of 0.70 T of the alloy $x = 35$ is near to the obtained value (1.19 T) for the amorphous alloy of similar composition $Fe_{38}Co_{34}Nb_6B_{11}Si_{10}Cu_1$, reported in Ref. 14.

4. Conclusions

The maximum MI ratios obtained for the alloys composition x = 35 and 40 were 10.3 % and 3.4 %, respectively. The difference between the obtained values can be attributed to the change in the magnetic structure of the material, when replacing Fe by Co, which affects the magnetic permeability and consequently the impedance of the material. The amorphous ribbons studied do not presented a GMI effect as that presented in Finemet and Co-based alloys. The dependence of the MI ratios with the frequency and the applied magnetic field is mainly due to electromagnetic skin effect. Magnetization measurements revealed the soft magnetic behavior of the alloys under study and an increase in saturation magnetization of the samples with higher Co content was obtained.

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