GIANT MAGNETOIMPEDANCE EFFECT IN THE $Co_{70}Fe_5Si_{15}B_{10}$ AMORPHOUS RIBBONS PRODUCED BY MELT SPINNING

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Abstract. *We developed a melt-spinning to produce metallic ribbons. The system is essentially made of a radio frequency oven generating 8 kVA of 450 kHz that was used to melt the compound, and a copper plate used to cool down the melting. The wheel can reach 3300 rpm in controlled atmosphere and yield cooling rate as high as* 10^6 *°C/s. The melt-spinning was used to produce the amorphous* $Co_{70}Fe_5Si_{15}B_{10}$ *alloy that is magnetically characterized for presenting high-magnetic permeability. XRD and EDS were used to characterize the microstructure of the ribbons. The giant magnetoimpedance (GMI) phenomenon was investigated in pieces of as-quenched ribbons by varying the length* $(5 \leq L \leq 100$ *mm) of the sample, the frequency* $(0.1 \leq f \leq 3$ *MHz) and amplitude of the AC electrical current* $(5 \leq I_{ac} \leq 50$ *mA), and the amplitude of a DC current* $(5 \leq I_{dc} \leq 50$*mA) applied simultaneously with the AC current. An anomalous behavior, characterized by a maximum, in the dependence of the GMI with L was observed yielding 107% was observed for L = 30 mm, f = 1 MHz e* $I_{ac} = 10$ *mA. For larger values of the L the asymmetry in the GMI induced by* I_{dc} *was found to be small but it become substantially large when L is reduced, yielding 165% for the GMI measured in a sample 30 mm long and with* $I_{dc} = 30$*mA.*

Keywords*: melt-spinning, amorphous ribbon, GMI*

1. INTRODUCTION

The phenomenon GMI has attracted considerable interest both from the theoretical viewpoint and from its wide technological applicability, e.g., for magnetic sensing or as an additional tool to investigate soft magnetic materials properties (Betancourt et al., 2005). This effect, consisting in a strong dependence of the ac impedance on a dc magnetic field has an electromagnetic origin and it is related to changes in the dynamics of the magnetization processes (Coisson, M. et al., 2003). By considering the general expression for the penetration depth $\delta = [\rho/\pi f \mu_T]^{1/2}$, where ρ is the sample electrical resistivity and f the electrical current frequency, it can be noted that the magnetic permeability μ (transversal, in the case of ribbons) plays a key role in the magnetoimpedance response (Appino, C. et al., 2004). As a consequence, GMI effect turns out to be very sensitive to composition (Nguyen Hoang Nghi et al., 2003), sample shape (Baradiaran, J. M., et al., 2002, Mendes, K. C. and Machado, F. L. A., 1998), annealing conditions (Prida, V. M., et al., 2003) and quenched-in internal stresses (Gómez-Polo, C., et al., 2002). Machado, F. L. A., et al., (1993), presented a theoretical model for the Co-rich amorphous ribbons based on the skin depth effect and on the domain motion due to the magnetic field and AC current, which explained the GMI spectra and its frequency and field dependence (Rahman, Z., et al., 2004). The GMI spectrum is essentially made of a pair of symmetric peaks with a maximum value occurring at magnetic fields of the order of few oersteds. It was also found that a large asymmetry is obtained when a dc electrical current is passed simultaneously with the ac one. This asymmetric GMI makes the phenomenon even more interesting for applications where both the magnitude and direction of the applied fields are desirable. Furthermore, higher sensitivity and linearity in the magnetic field dependence are obtained when asymmetry is induced in the GMI (Kim, C. G., et al., 1999). Asymmetric GMI due to the dc electrical current was observed in wires (Kitoh., T., et al., 1995, Machado, F. L. A., et al., 1999) and ribbons of magnetic amorphous alloys (Song, S. H., et al., 1999). In this work, we present a detailed investigation of the GMI in the magnetostrictive $Co_{70}Fe_5Si_{15}B_{10}$ alloying a broad range of frequency (f) and amplitude (I_{ac}) of the ac electrical current, length (L) of the ribbon, and magnitude (I_{dc}) and direction of a dc electrical current used to induce asymmetry in the GMI.

2. SAMPLES AND EXPERIMENTAL TECHNIQUES

Amorphous magnetostrictive alloy of nominal composition $Co_{70}Fe_5Si_{15}B_{10}$ was prepared by the conventional melt-spinning technique in an argon atmosphere. Pieces of 60 μm thick and 1,5mm wide of this ribbons amorphous were cut in as quenched samples for $5<L<100$mm.

The samples were characterized by x-ray diffraction using the Cu-Kα radiation and by energy dispersive x-ray analysis (EDS). We found that the samples are homogeneous in both composition and degree of amorphousness. A phase sensitive four-probe technique was used to measure the room temperature magnetoimpedance *Z(H).* The frequency and amplitude of the ac electrical current and the magnetic field, applied along the length of the sample, were varied in the ranges $0.1 \leq f \leq 3$MHz, $5 \leq I_{ac} \leq 50$mA, $-30 \leq H \leq 30$Oe, respectively. In order to investigate the asymmetric GMI in this alloy, a dc electrical current was applied simultaneously with the ac one with magnitudes that were in the range $5 \leq I_{ac} \leq 50$mA. The low frequency ac susceptibility χ_{ac} was measured as a function of H using a first-order gradiometer coil system.

3. EXPERIMENTAL RESULTS

All the data were obtained for f = 10 Hz leading to a value of χ_{ac} that is quite close to the dc one. The room temperature χ_{ac} was measured as a function of H for as-quenched samples for several values of L and for f = 10 Hz. The results are shown in Fig. 1. The data were normalized by the length of the samples to eliminate the filling factor contribution since the signal induced in the pick-up coil is proportional to the volume of the sample which, in this case, varies due to the change in l. The inset in Fig. 1 is plot of the χ_{ac} vs. T data, obtained for L= 30 mm and for f = 10 Hz, which shows that our sample become ferromagnetic below 586 K.

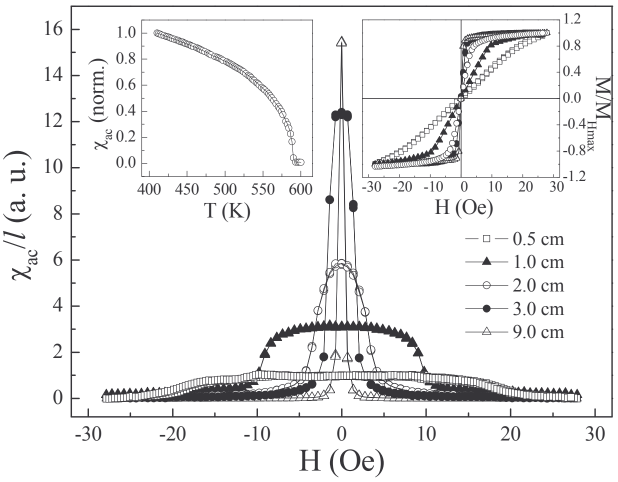

Fig. 1 – χ_{ac} vs. H for $Co_{70}Fe_5Si_{15}B_{10}$ amorphous ribbons

The percent GMI (%), defined as $10^2[Z(H) - Z(H_{max})]/Z(H_{max})$, where $Z(H_{max})$ is the magnetoimpedance measured at the maximum value of H, is shown in Fig. 2 for L = 30 mm, I_{ac} = 10 mA and for several values of f. GMI as high as 107 % is obtained at room temperature for f = 1.0 MHz.

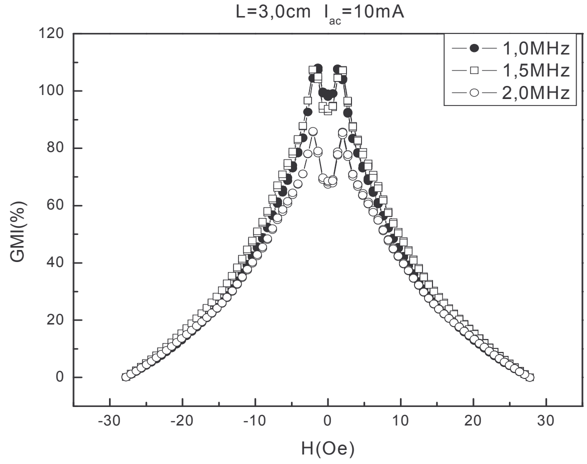

Fig. 2. – GMI spectra for $Co_{70}Fe_5Si_{15}B_{10}$, measured at different values of frequency.

In Fig. 3 it is shown the GMI for I_{ac} = 10 mA and f = 1.0 MHz while the length of the sample is varied. The value of the H where the GMI reaches its maximum (H_{max}) diminishes rapidly from 8.8Oe for L= 10 mm to 1.3Oe for L =30 mm.

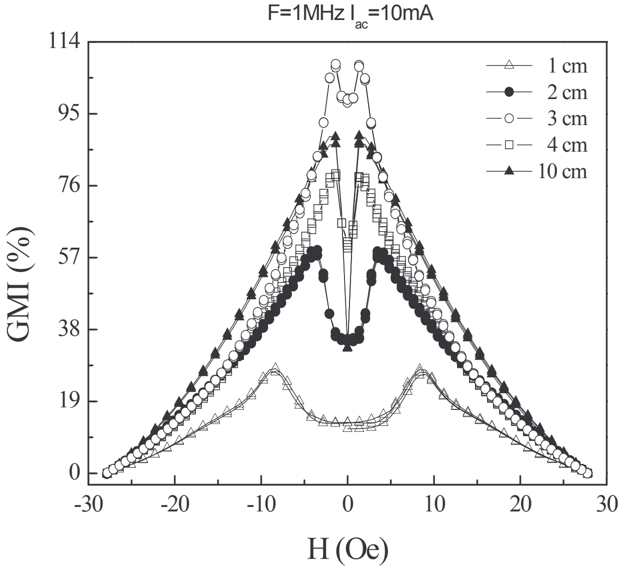

Fig. 3 – GMI spectra for $Co_{70}Fe_5Si_{15}B_{10}$ measured at different values of *L*.

In Fig. 4 it is plotted the asymmetric GMI measured with I_{ac} = 10 mA, I_{dc} = 30 mA, f = 1.0 MHz and for several values of *L*. The asymmetric GMI, induced by I_{dc}, was found to increase when *L* diminishes and it reaches 165% for *L*=30mm and I_{dc}=30mA. For larger values of *L* the asymmetric in the GMI diminishes. The asymmetry is strongly dependent on the values of these parameters.

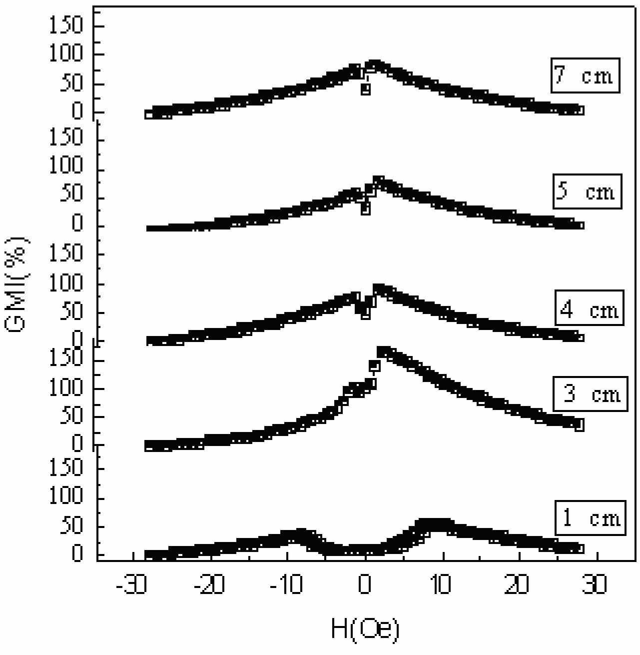

Fig. 4 – Asymmetric GMI for different values of *L*.

4. DISCUSSION AND CONCLUSIONS

The GMI is a phenomenon essentially due the skin-depth effect and to its dependence on the magnetic permeability $\mu_T = (1 + \chi_{ac})$. Because of the high magnetic permeability of these samples, δ is relatively small compared to the thickness of the sample, and the electrical current flows near the surface of the sample. An increase in H diminishes μ_T due to the magnetic saturation of the sample. Thus, the current is driven towards the bulk of the sample. As shown above, it has also been found a nice correlation between the general behavior of χ_{ac} and the GMI despite the fact that relevant χ_{ac} for the GMI is the transversal one that couples the magnetic field due to the current to the magnetization of the material. This happens so because χ_{ac} is somewhat isotropic in these materials. It is worth to mention that even though the GMI is measured in a much higher frequency, the H-dependence of μ_T is mainly determined by the dc magnetic susceptibility. The frequency dependence is in agreement with that expected for a high magnetic permeability material. The observed anomalous L-dependence in the GMI is initially interpreted as due to an increase in the demagnetizing factor (N) along the direction of the length of the sample when L is reduced. An increase in N favors the formation of domains, which reduce the overall magnetic permeability and the GMI but, for L=30mm, we believe that the domain configurations favors an increase in the transversal magnetic permeability and in the GMI.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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