Available online at www.sciencedirect.com
ScienceDirect
Journal of Non-Crystalline Solids 353 (2007) 908–910
JOURNAL OF NON-CRYSTALLINE SOLIDS
www.elsevier.com/locate/jnoncrysol

Angular dependence of low-field microwave absorption in Co-rich amorphous alloys

H. Montiel [a,*], G. Alvarez [b], R. Zamorano [c], R. Valenzuela [b]

[a] *Dep. de Ciencias Aplicadas, Centro de Ciencias Aplicadas y Desarrollo Tecnológico de la Universidad Nacional Autónoma de México, México D.F. 04510, Mexico*

[b] *Dep. de Materiales Métalicos y Cerámicos, Instituto de Investigaciones en Materiales de la Universidad Nacional Autónoma de México, México D.F. 04510, Mexico*

[c] *Escuela de Física y Matemáticas del Instituto Politécnico Nacional, México D.F. 07738, Mexico*

Available online 12 February 2007

Abstract

Microwave power absorption measurements at 9.4 GHz (X-band) were carried out on as-cast amorphous ribbons of nominal composition $Co_{66}Fe_4B_{12}Si_{13}Nb_4Cu$, prepared by melt spinning. The angular dependence of low-field absorption (LFA) was investigated from $\theta = 0°$ to 180° in two orientations. In both cases the ribbon axis was orientated parallel to the DC magnetic field. In orientation 1, the ribbon plane was parallel to the AC microwave field. In orientation 2, it was perpendicular to the AC field. LFA spectra showed an antisymmetric shape (a minimum and a maximum), whose separation increased as a function of the angle between the DC field and the ribbon axis. A similar angular behavior was observed for the resonance field of the ferromagnetic resonance (FMR). For the orientation 1, the resonance field increased as a function of the angle, which can be explained in terms of the contribution of the shape anisotropy to the total anisotropy field. A similar behavior was observed in LFA, which suggests that the shape anisotropy field can be observed in the angular dependence of LFA. In the orientation 2, the observed changes occur within the plane associated with the induced anisotropy due to the rapid solidification process. The LFA signal is capable therefore to detect different contributions to the total anisotropy.

PACS: 75.50.Kj; 75.47.−m; 75.50.Bb; 78.70.Gq

Keyword: Resonance methods

1. Introduction

Low-field microwave absorption (LFA) has been observed in a wide variety of materials: high-temperature superconductors, semiconductors, and recently in ferromagnetic materials. For high-temperature superconductors, the appearance of this absorption has been widely accepted as a signature of the transition to the superconductive state; and this LFA signal is associated with the dissipative dynamics of fluxons [1,2]. For semiconductors, the LFA signal is due to magnetoresistive phenomena that are responsible for most of the magnetic field dependences of the microwave absorption [3]. For manganites and ferrites, the appearance of LFA is associated with the onset of the ordered phase and provides a sensitive detector of magnetic ordering [4,5]. The existence of LFA signal has been reported previously in other soft magnetic materials and has been interpreted as due to low-field spin magnetization processes [6,7].

In this paper, we investigated the angular dependence of LFA and ferromagnetic resonance (FMR) behavior of Co-based as-cast amorphous ribbons when subjected to high frequency fields at 9.4 GHz (X-band). Additionally, a comparison is made between the angular dependence of LFA signal and FMR measurements, exhibiting a good correla-

* Corresponding author. Tel./fax: +52 55 56228616.
E-mail address: herlinda_m@yahoo.com (H. Montiel).

0022-3093/$ - see front matter
doi:10.1016/j.jnoncrysol.2006.12.059

tion, which is underpinned by the total anisotropy of the ribbon.

2. Experimental

As-cast amorphous ribbons, 2 mm wide and 22 μm thick, of nominal composition $Co_{66}Fe_4B_{12}Si_{13}Nb_4Cu$, were prepared by melt-spinning at a tangential speed of 45 m/s. Their amorphous state was confirmed by X-ray diffraction.

The ferromagnetic resonant absorption (FMR) of the samples were measured using a Jeol JES-RES3X spectrometer operating at 9.4 GHz (X-band). The AC signal power was 1 mW. For low-field absorption (LFA), we used additionally a Jeol ES-ZCS2 zero cross sweep unit which compensates digitally for any remanence in the electromagnet, thus allowing measurements to be carried out by cycling the DC magnetic field around its zero value continuously from −1 to 1 kOe, with a standard deviation of less than 0.2 Oe for the measured field.

3. Results and discussion

The angular dependence of LFA for the orientation 1 is shown in Fig. 1. For clarity, the spectra show variations in LFA signal only from 0° to 90°. For 0°, the AC microwave field is parallel to the ribbon plane and DC field is parallel to the ribbon axis. For 90°, the AC field remains parallel to the plane, while DC field becomes normal to the ribbon plane. LFA spectra showed an increase in the width ΔH_{LFA}, for angle variations of 0° to 90°, where ΔH_{LFA} is the separation between their maxima and minima. In addition, the intensity of the signal decreases when increasing the angle up to 90°. For angles $90° < \theta < 180°$, a symmetric decrease is observed for these angles. The inset of Fig. 1 shows FMR measurements, carried out in the same geometries, leading to variation in the resonant field as a function of DC field orientation. The angular dependence of the resonant field (H_{res}) can be observed with a shift to the largest field, the maximum shift occurring at 90°. This behavior can be explained by means of the shape anisotropy field (SAF) and correspond the energy needed to orientated the magnetic moment in the hardest direction, this is outside of the plane. For 0°, SAF is a minimum because the magnetization remains within the plane. When the DC is parallel to the ribbon's plane, variations in ΔH_{LFA} should be mainly associated with the induced anisotropy. In consequence, the total field anisotropy has an additional contribution due to SAF and change the ΔH_{LFA} of LFA signal.

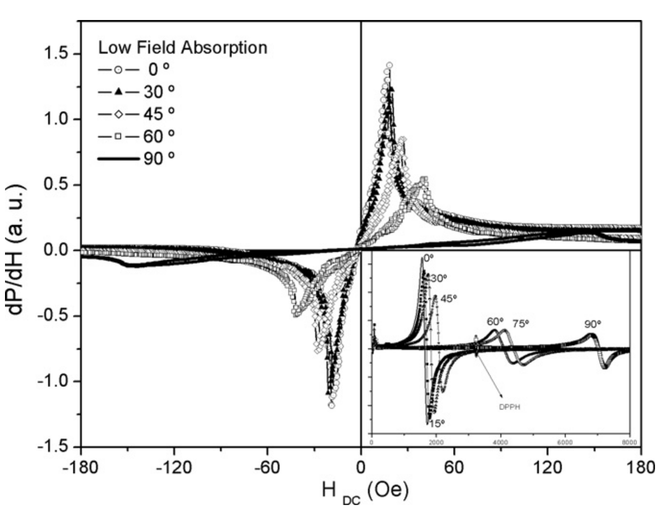

Fig. 1. Angular dependence of low-field microwave absorption for orientation 1; for clarity, only results from 0° to 90° are shown. The inset shows angular variations of FMR.

Fig. 2 shows the angular dependence of LFA signal for the orientation 2 for variations from 0° to 90°. For 0°, the AC microwave field is perpendicular to the ribbon plane and DC field is parallel to the ribbon axis. For 90°, AC field remains perpendicular to the plane and DC field is perpendicular to the ribbon axis. A square cycle (SC) with hysteresis is observed in the center of LFA signal, as well as a clear maximum and minimum (ΔH_{LFA}). The area of SC decreases while ΔH_{LFA} increases for angle variations of 0° to 90°. The angular dependence of LFA can be separated in two contributions: one relative to SC and the other to ΔH_{LFA}. FMR measurements were also carried out in the same geometries as a function of DC field orientation. The angular dependence of the H_{res} shows a shift to small

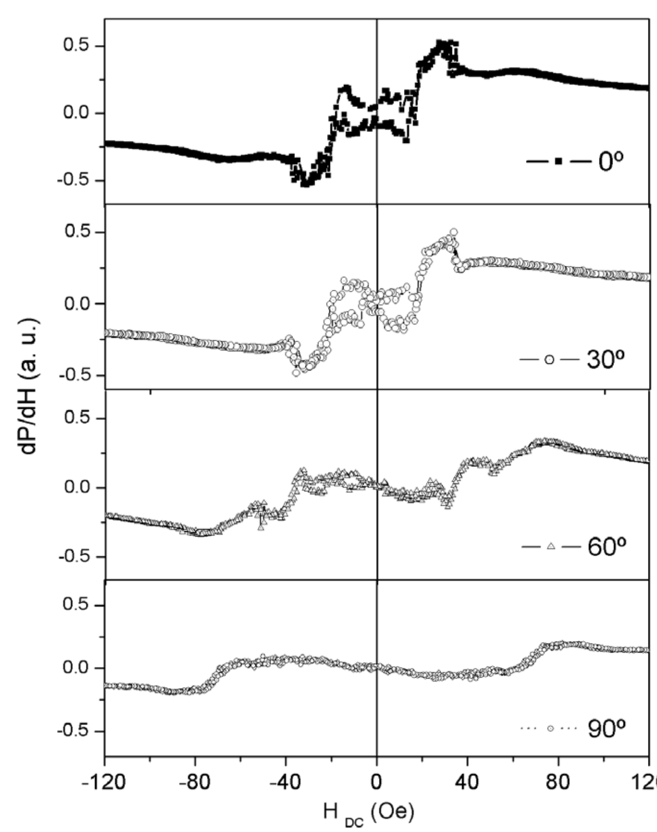

Fig. 2. Angular dependence of low-field microwave absorption in orientation 2, from 0° to 90°.

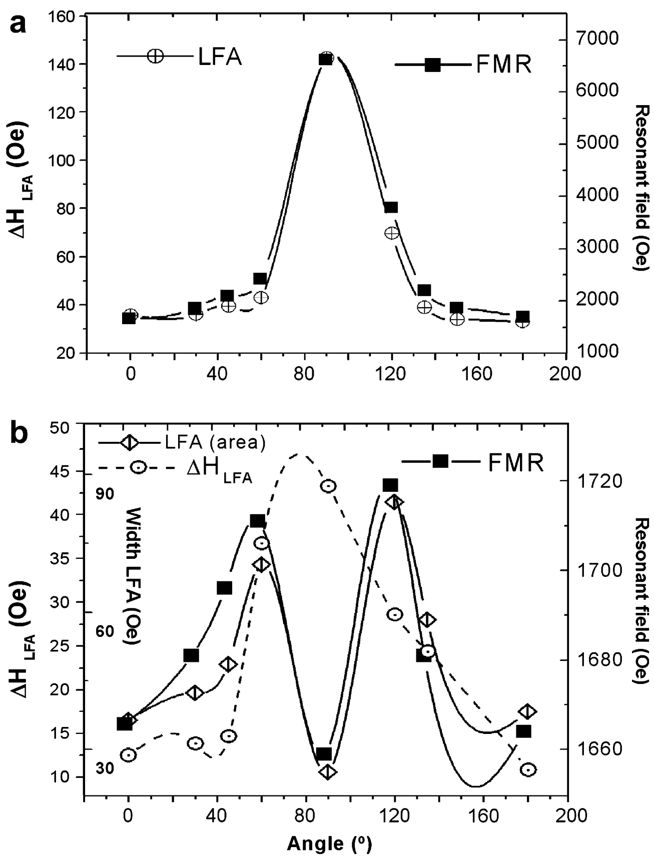

Fig. 3. Angular dependence of LFA and FMR from 0° to 180° (a) for orientation 1 and, (b) for orientation 2.

fields. Angular variations of DC led to a similar behavior of FMR, and present a minimum at 90° and maximum at 60° and 120°; this behavior is due to intrinsic anisotropy field (IAF). The angular variation of $\Delta H_{\mathrm{LFA}}$is similar to orientation 1, which suggests that this behavior is induced by SAF.

We compared the angular variations of ΔH_{LFA} and H_{res} for both orientations in Fig. 3. The same angular dependence is observed in LFA and FMR for orientation 1 Fig. 3(a), even though it is due to different processes. LFA is originated by magnetization processes far from the saturation state and is very similar to that of giant magnetoimpedance (GMI) [6], while FMR signal is due to absorption in the full saturation state and corresponds to the quantum-mechanical resonant phenomenon. Both signals, however, are modulated by total anisotropy field, including SAF and IAF. Fig. 3(b) shows ΔH_{LFA} and H_{res} angular variations for orientation 2; they also have a similar angular dependence. In this orientation, the SAF is minimized but not eliminated. In consequence, it is possible to separate angular variations of IAF and SAF. It is interesting to note that the orientation of the AC field propagation also affects the response of absorption. The propagation is more complex when it is perpendicular to the ribbon plane than when it is in the cross section of the sample.

4. Conclusions

The angular dependence of the magnetic anisotropy field can be correlated with the angular dependence of the LFA separation. LFA experiments are proposed as a sensitive method to determine different contributions to the total anisotropy field.

References

[1] G.K. Padam, S.N. Ekbote, Malay Rajan Tripathy, G.P. Srivastava, B.K. Das, Physica C 315 (1999) 45.
[2] G. Alvarez, R. Zamorano, J. Alloys Compd. 369 (2004) 231.
[3] A.I. Veinger, A.G. Zabrodskii, T.V. Tisnek, Phys. Stat. Sol. (b) 218 (2000) 189.
[4] H. Montiel, G. Alvarez, M.P. Gutiérrez, R. Zamorano, R. Valenzuela, J. Alloys Compd. 369 (2004) 141.
[5] J. Owens, J. Phys. Chem. Sol. 58 (1997) 1311.
[6] H. Montiel, G. Alvarez, I. Betancourt, R. Zamorano, R. Valenzuela, Appl. Phys. Lett. 86 (2005) 072503.
[7] R.S. Beach, A.E. Berkowitz, J. Appl. Phys. 76 (1994) 6209.