

Deconvolution of ferromagnetic resonance in devitrification process of Co-based amorphous alloys

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Abstract

Ferromagnetic resonance (FMR) measurements were carried out on soft magnetic amorphous ribbons of composition $\text{Co}_{66}\text{Fe}_4\text{B}_{12}\text{Si}_{13}\text{Nb}_4\text{Cu}$ prepared by melt spinning. In the as-cast sample, a simple FMR spectrum was apparent. For treatment times of 5–20 min a complex resonant absorption at lower fields was detected; deconvolution calculations were carried out on the FMR spectra and it was possible to separate two contributions. These results can be interpreted as the combination of two different magnetic phases, corresponding to the amorphous matrix and nanocrystallites. The parameters of resonant absorptions can be associated with the evolution of nanocrystallization during the annealing.

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1. Introduction

Nanocrystalline ferromagnets obtained by crystallization of amorphous alloys are an important group of soft magnetic materials [1–3]. These materials consist of nanocrystallites randomly nucleated in soft amorphous matrices. The magnetic softness has been explained by Herzer [4], with the aid of the exchange correlation length for randomly distributed local easy axes that correspond to the average crystalline size. These materials are employed at frequencies of microwaves [5]; therefore it is important to know the properties of these materials at high frequencies.

Ferromagnetic resonance (FMR) measurements are useful for determining the anisotropy field and magnetic parameters [6,7]. Among the magnetic parameters, which determine the overall working conditions are: the resonant

field (H_{res}), the linewidth of the absorption and saturation magnetization and the double integral of the absorption [7]. In addition, these techniques allow the detection of different magnetic phases [6].

In this paper, we present FMR spectra obtained on Co-rich amorphous ribbons with different nanocrystallization states. We fit the FMR signal (deconvolution) at two absorption modes, corresponding to two ferromagnetic phases associated with the nanocrystalline phase and the amorphous matrix. Thus, it is possible to separate the response of the two components. And we obtain different behavior in the H_{res} during the several stages of nanocrystallization for both lines. The changes in this parameter is associated with the evolution of microstructure for different stages of nanocrystallization.

2. Experimental procedure

Melt-spun $\text{Co}_{66}\text{Fe}_4\text{B}_{12}\text{Si}_{13}\text{Nb}_4\text{Cu}$ soft magnetic ribbons, obtained at a tangential roll speed of 40 m/s were devitrified at low-annealing temperatures (623 K), for times of 5, 10,

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15 and 20 min. Their initial amorphous state was checked by X-ray diffraction. FMR measurements were made on samples of 3 mm wide and 22 mm thick, using a Jeol JES-RES3X spectrometer operating at 9.4 GHz (X-band). The power of the AC signal was 1 mW. The FMR spectra were obtained by the DC magnetic field modulation technique, with a modulation frequency of 100 kHz. All spectra were taken at room temperature with a standard deviation of the measured field of less than 0.2 G.

3. Results and discussion

The FMR spectra for the devitrified alloys $\text{Co}_{66}\text{Fe}_4\text{B}_{12}\text{Si}_{13}\text{Nb}_4\text{Cu}$ at different annealing times are shown in Fig. 1. The as-cast amorphous sample shows a single FMR absorption, A; the linewidth of this absorption suggests the possibility of the presence of a second signal. The absorption A is observed in all FMR spectra for all annealing times. At the annealing time of 5 min, a new absorption, B, appears at a slightly lower field. For annealing times of 10, 15 and 20 min the absorption B grows and clearly becomes a second absorption signal. We can associate this second resonant absorption B to the new magnetic phase, namely the nanocrystalline phase.

The FMR spectra were fitted to a functional form similar to that used by Ivanshin et al. [8]. The derivative power absorption is

$$\frac{dP}{dH} \propto \frac{d}{dH} \left(\frac{\Delta H_{pp} + \alpha(H - H_{res})}{(H - H_{res})^2 + \Delta H_{pp}^2} + \frac{\Delta H_{pp} + \alpha(H + H_{res})}{(H + H_{res})^2 + \Delta H_{pp}^2} \right), \quad (1)$$

where α is the asymmetry parameter, it is the dispersion to absorption ratio and ΔH_{pp} is the linewidth.

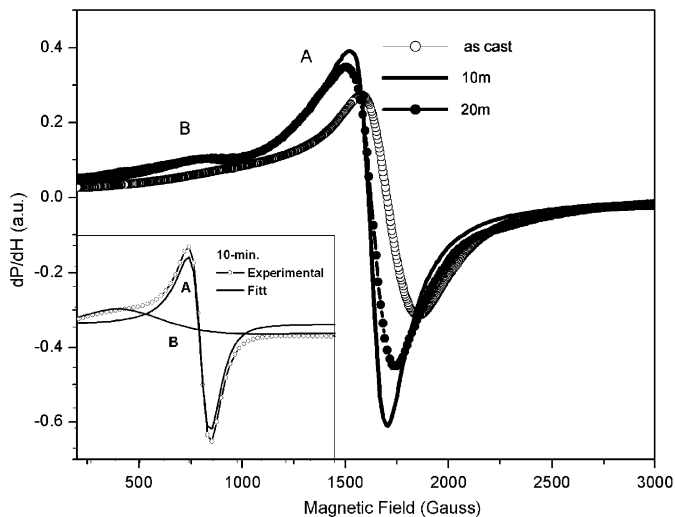


Fig. 1. FMR spectra of Co-rich amorphous ribbons with different nanocrystallization stages for selected annealing temperatures. The inset shows deconvolution of FMR spectra at 10 min of annealing. Absorption A corresponds at amorphous matrix and absorption B is associated with nanocrystallites.

By means of this fitting, it was then possible to separate two contributions of the form (1) to the total absorption, see inset in Fig. 1, and lineshape parameters are then obtained. We can then follow the dynamics of nanocrystallization as a function of the annealing time. Inset in Fig. 1 shows the deconvolution for the annealing time of 10 min. In this figure, the FMR spectra clearly exhibits two modes of absorption, corresponding to signal A associated to the amorphous matrix, and absorption B, associated to nanocrystallites.

In ferromagnetic materials the FMR absorption satisfies the condition $\omega = \gamma H_{res}$, where $\gamma = ge/2m$ is magnetogyric ratio. This field is the addition of applied H_{DC} an internal field H_I [6]. For a system of randomly oriented nanocrystallites of ferromagnetic material, a first order approximation yields:

$$H_{res} = H_{DC} - H_I \quad (2)$$

with $H_I = -H_K + H_d + H_j$, where H_K represents the anisotropy field, H_d is the demagnetization field and H_j is the exchange field. The internal field adds to the applied field and the resonant condition for a fixed frequency is reached at values of H_{DC} smaller than the initial- H_{DC} field.

Fig. 2a shows the annealing time dependence of H_{res} for the absorptions due to the amorphous matrix and nanocrystallites. The resonant field for the nanocrystallites decreases as the annealing time it is increased until 10 min of annealing and corresponds to a minimum of H_{res} . For the amorphous matrix, the H_{res} shows a small decrease at 10 min. This point in the annealing (Fig. 2a) corresponds to a magnetic softening preceded by a small magnetic hardening. This behavior in H_{res} can be correlated to the annealing dependence of coercivity field H_c as function of annealing time (Fig. 2b). Here, the minimum of H_c

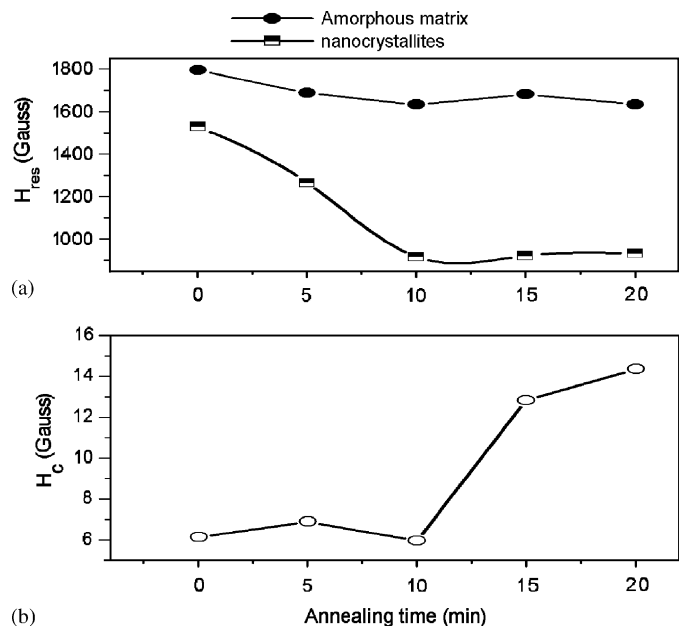


Fig. 2. Effects of annealing time on (a) H_{res} , (b) coercivity field (H_c).

corresponds a minimum in H_{res} . This can be explained by considering that the number of nanocrystallites is very small (for as-cast and 5 min of annealing), and therefore the average distance between nanocrystallites is much larger than the exchange correlation length between them across the amorphous matrix. By increasing the annealing time at 10 min, the average distance between nanocrystallites decreases and consequently, the exchange correlation length becomes larger than the structural correlation length in thus, the anisotropy goes to a minimum as predicted by the model of Herzer. This minimum in the anisotropy field is associated with a minimum of H_{res} according to Eq. (2). This suggests that the total anisotropy field it is constituted by the contribution of anisotropy field of nanocrystallites and amorphous matrix. Besides, from deconvolution it is possible to establish that the anisotropy field of nanocrystallites is a dominant contribution for the total anisotropy field. Therefore the strong dependence of the internal field on total anisotropy field can be reflected in resonance absorption FMR.

For longer annealing times (15 and 20 min) H_{res} shows a minimum value, this behavior is obtained both for amorphous matrix and nanocrystallites. The fact that the as-cast sample showed also two absorptions that can be interpreted in terms of the precursor phase of nanocrystallization.

4. Conclusions

From deconvolution of the FMR spectra of annealed samples, it is possible to separate two contributions, corresponding to the amorphous matrix and the nanocrystallites. The main change in the parameters of the resonant absorption as the nanocrystallization increases can be associated the anisotropy field.

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