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Physica B 354 (2004) 104–107
PHYSICA B
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Ferromagnetic resonance and magnetic properties of single-domain particles of $Y_3Fe_5O_{12}$ prepared by sol–gel method

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Abstract

We present ferromagnetic resonance (FMR) and magnetic properties of single domain $Y_3Fe_5O_{12}$ (YIG) nanoparticles with an average size of 60 nm. The saturation magnetization shows a diminution of practically $\frac{1}{3}$ of the bulk magnetization due to the surface/volume contribution. The coercive force vs. temperature indicates that the particles are single magnetic domains in the blocked state. The FMR data, confirm this state below 350 K. Data of DC-magnetization, magnetic resonance field and linewidth of the FMR spectra are presented. Shape, surface and dipolar contributions to effective anisotropy are discussed.

PACS: 76.50.+g; 75.50.Tt; 75.75.+a

Keywords: Ferromagnetic resonance; Small particles; Yttrium iron garnet

1. Introduction

In spite of the fact that ferromagnetic garnet is a very well-known material and it is also widely used in electronic devices, new applications emerge nowadays as component of synthesizers for digital radios, of transmission lines information in integrated optical modulators and of magneto-optical information storage by dispersion of nanocrystals on glass [1]. In the previous works we synthesized, characterized [2–4] and studied in depth the magnetic behavior of particles with different average size (D) [5]. Surface effects were observed in the saturation magnetization (M_s), which presents a linear dependence with the surface/volume ratio. The dependence of the coercivity (H_C) with D define the region for single magnetic domain in the blocked state and it was determined between 35 and 190 nm [5].

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doi:10.1016/j.physb.2004.09.028

In this paper, we focus our attention on the magnetic properties and the ferromagnetic resonance (FMR) of a powder sample with an average particle size of 60 nm.

2. Experimental

The powder samples were prepared by the sol–gel method. From an aqueous solution of citric acid and nitrates of iron (III) and yttrium (III), which is heated at 380 K for 2 h for drying the gel and forming a powder. The synthesis of the garnet oxide is reached within a further annealing treatment, which is performed in air at 1023 K for 2 h obtaining particles around 60 nm. X-ray diffraction was used to check the phase formation, and to determine the mean crystallite sizes from the linewidth X-ray peaks using the Scherrer relation. These sizes were confirmed by transmission electron microscopy.

Magnetization data were recorded at low magnetic fields after the sample was cooled in zero magnetic field (ZFC) or under the magnetic field (FC). In the low-temperature range (5–300 K), we used a SQUID magnetometer, while for temperatures above room temperature (298–650 K), the data were collected in a commercial vibrating sample magnetometer.

FMR spectra were taken at 9 GHz in a Bruker spectrometer between 120 and 500 K.

3. Results

ZFC and FC magnetization are in Fig. 1. A notable increase of both magnetizations occurs at the Curie temperature $T_C = 550$ K. At $T_B \sim 420$ K, the FC data shifts from the ZFC magnetization curve by the blocking of the particle moments. The maximum value of the ZFC magnetization is at approximately 350 K, near of T_B. This can evidence a distribution of particle volumes. On the other hand, the fact that these characteristic temperatures are above room temperature is well confirmed by the irreversibility between the M_{ZFC} and M_{FC} magnetizations, which were measured below 300 K (see inset of Fig. 1).

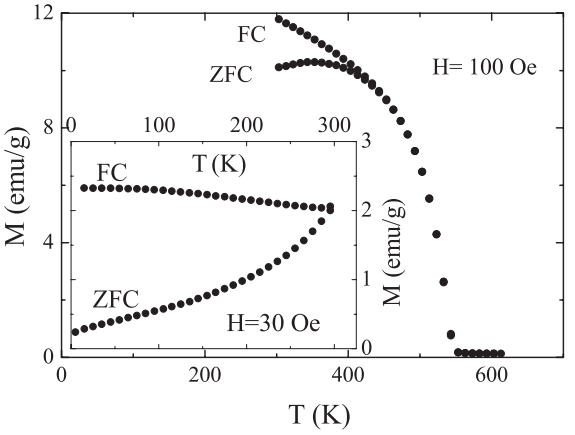

Fig. 1. Magnetization versus temperature after zero field cooling and field cooling conditions. Both were taken under a magnetic field of 100 Oe. The shift between both curves corresponds to the blocking temperature (400 K). In the inset the magnetization curves at low temperatures are shown in detail. The data were taken at 30 Oe.

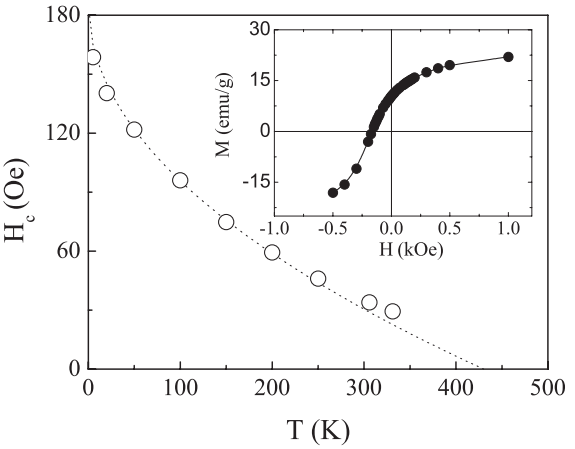

Fig. 2. Coercive field at different temperatures. The dotted line is the $T^{1/2}$ dependence. The inset shows the magnetization versus H at 5 K. The coercivity is approximately 160 Oe.

The inset of Fig. 2 shows the magnetization (M) of the sample at 5 K. The coercivity can be appreciated, which is around 160 Oe. In accord with the expected behavior for single magnetic domains, the H_C reduction with the increase of temperature which can described by

$H_C = H_C^0[1 - \sqrt{(T/T_B)}]$ (dot line in Fig. 2) where H_C^0 is the coercive force at $T = 0$ K.

FMR spectra at different temperatures between 120 and 440 K are shown in Fig. 3. At high temperatures, the line is completely symmetric with a peak-to-peak linewidth (ΔH_{pp}) of 150 Oe. The resonance magnetic field (H_r) is approximately 3350 Oe, which corresponds to a gyromagnetic factor of 2.010 (paramagnetic bulk material is 2.004 [6]). Temperature dependence of ΔH_{pp} and H_r is in Fig. 4. To avoid dipolar interactions among the particles, dilutions 1:10, 1:50 and 1:100 were performed in an epoxi resin and we have not observed significantly changes in H_C and ΔH_{pp}. Below T_C, H_r decreases due to the action of an internal field ($H_i = H_r - H_0$) as can be seen in the bottom of Fig. 4. At 120 K, ΔH_{pp} reaches 650 Oe and H_r diminishes by 100 Oe. The YIG material is an archetypal of low crystalline anisotropy [6,7]. For a clean system (without contributions of the dipolar interactions, the shape, and the surface), H_C and H_i should be at lower temperatures $2K_1/M_s = 85$ Oe, but the experimental value is higher than this, which indicates the presence of an extra contribution to H_A. A best estimation of the anisotropy field (H_A) can be taken $\frac{2}{3}$ of the variation of the linewidth [8], which is around 330 Oe for this system. Due to the aspect ratio of the particles is around 2:1, it suggests that a shape contribution of approximately 290 Oe is present in the system. The sum of both contributions, crystalline and shape, is near to the predicted value from the linewidth. On the other hand, we cannot discard the presence of surface effect on H_A. Finally, we conclude that the crystalline and shape contributions to H_A can be responsible for the experimentally observed anisotropy in YIG single magnetic domain particles.

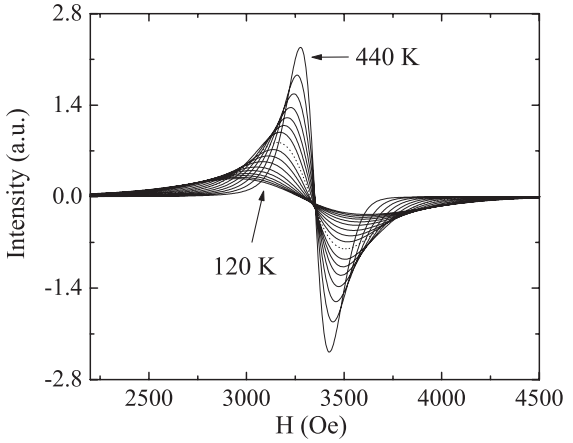

Fig. 3. Temperature evolution of the FMR line between 120 and 440 K of nanoparticles of 60 nm.

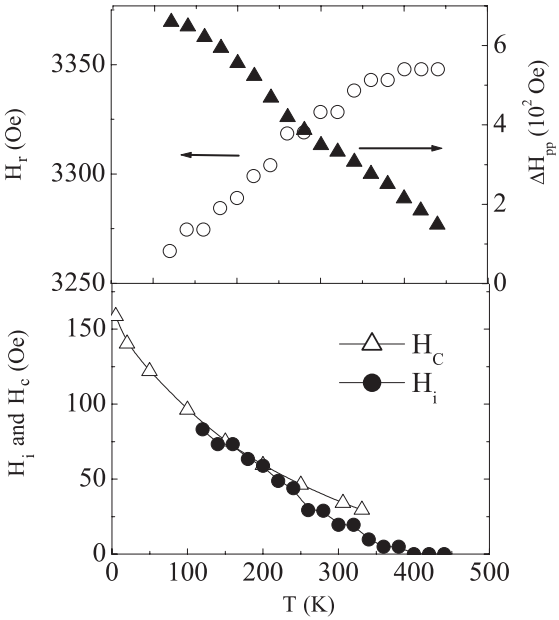

Fig. 4. Temperature dependence of the resonance magnetic field (H_r) and linewidth (ΔH_{pp}) in the upper panel. In the bottom, H_i and H_C as a function of temperature.

Acknowledgments

We acknowledge support from CNEA, Conicet, Fundación Antorchas and ANPCyT PICT 05266.

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