

Anisotropy field and transverse susceptibility in nanocrystalline hexaferrites

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Abstract

Nanocrystalline strontium and barium hexaferrites were produced by an ionic coordination reaction method. The average particle size obtained using the Rietveld X-ray refinement technique and by scanning electron microscopy was quite uniform and close to 50 nm. Transverse susceptibility measurements yielded both the coercive and the anisotropy magnetic fields. The results were analysed using a theoretical model proposed by Aharoni et al. [Bull. Res. Council. Isr. A 6 (1957) 215]. This overall procedure seems to be quite useful in determining the distribution of the anisotropy magnetic fields in granular materials.

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1. Introduction

Nowadays, there has been an increasing interest in strontium and barium hexaferrites because of their application in perpendicular magnetic recording [1]. These hexaferrites present both high magnetocrystalline anisotropy and chemical stability [2]. However, some other requirements are desirable. The fine hexaferrite particles must be single-magnetic domain particles, they need to be chemically homogeneous, and exhibit a high saturation magnetization and large coercivity, and one needs to be able to prepare them with a narrow-size distribution with good dispersibility.

In order to produce this type of materials, chemistry-based novel synthesis routes, including hydrothermal method [3], sol-gel and salt-melt techniques [4], chemical co-precipitation [5], aerosol pyrolysis [6], glass crystallization [7], colloidal synthesis [8], process mediated by microemulsion [9], for instance, have been used. These

techniques have few points in common, e.g., they start from mixtures of materials in an ionic level and they process the crystallization at relatively low temperatures, obtaining small particles.

In this work, we produced ultrafine single-domain particles of strontium and barium hexaferrites using a new process of synthesis [10] that is based on the ionic coordination reaction (ICR) technique. The size of the particles was determined from X-rays diffraction and scanning electron microscopy (SEM) images yielding a narrow-size distribution. From the magnetization and from the transverse magnetic susceptibility data we determined the coercive and the anisotropy magnetic fields of the particles.

2. Experimental

Powders of SrFe₁₂O₁₉ and BaFe₁₂O₁₉ were prepared by the ICR technique using the atomic ratio of 1(Sr,Ba):11.5(Fe). The starting solution was prepared by adding a chitosan solution to the Sr(Ba) and Fe nitrates

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dissolved in water. This mixture was then burned at ambient atmosphere for 4 h at a temperature of 350 °C, yielding the precursor powder that was calcinated for 1 h at a temperature of 800 °C. After the calcination process is completed one gets a brownish fine powder. The structural characterization of the grains was analysed by X-rays diffraction (XRD) using the Cu-K α radiation in a Rigaku diffractometer. The samples were also analysed by SEM. The magnetization of the samples was measured using a vibrant sample magnetometer while transverse susceptibility was measured using a low-frequency (10 kHz) AC susceptometer.

3. Results and discussion

Fig. 1 shows the XRD patterns of the precursors and of the calcinated barium and strontium hexaferrite samples. The XRD analysis indicated the presence of γ -Fe $_2$ O $_3$ and SrCO $_3$ (Fig. 1(a)), and of BaCO $_3$ (Fig. 1(b)) in the strontium and barium hexaferrite precursor powders, respectively. However, pure crystalline phases of SrFe $_{12}$ O $_{19}$ (Fig. 1(c)) and BaFe $_{12}$ O $_{19}$ (Fig. 1(d)) were obtained in the powders calcinated at 800 °C. The Rietveld refinement of the XRD patterns showed that the single-hexaferrite phases had a hexagonal crystal structure with a P6 $_3$ /mmc space group. The lattice parameters for the barium and for the strontium hexaferrites are $a_0 = 5.884$ Å, $c_0 = 23.074$ Å, and $a_0 = 5.894$ Å, $c_0 = 23.215$ Å, respectively. Further-

more, the refinement yielded an average particle size D_m of 51 nm for the barium hexaferrite while for the strontium one D_m was 57 nm. A SEM image obtained for the BaFe $_{12}$ O $_{19}$ powder is shown in Fig. 2. Note that grain sizes are indeed close to 50 nm as determined from the X-ray analysis.

The room temperature hysteresis loops for the barium and strontium hexaferrites are shown in Fig. 3(a). The magnetization measured at the highest applied magnetic

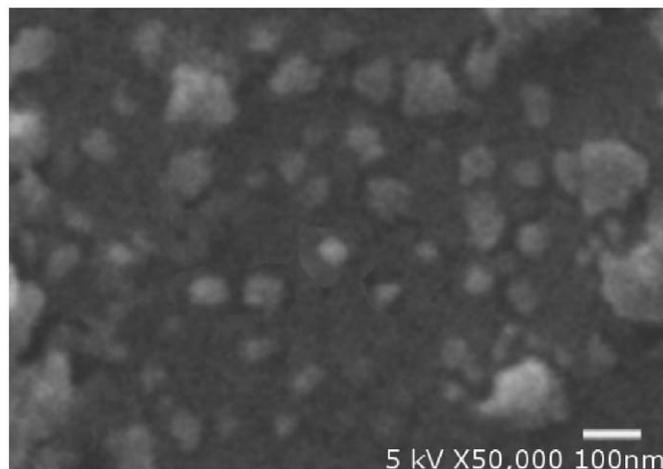


Fig. 2. SEM image for the BaFe $_{12}$ O $_{19}$ powder calcinated at 800 °C.

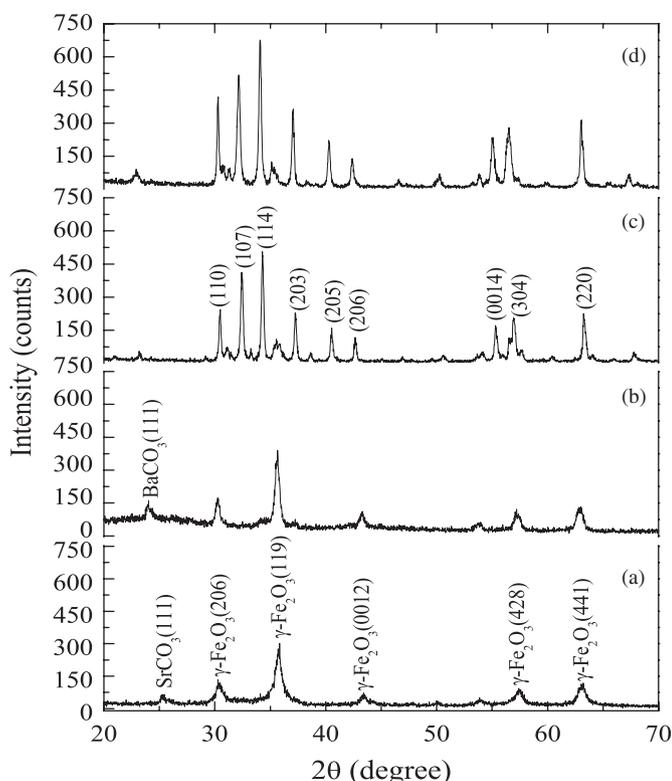


Fig. 1. X-ray diffractograms obtained for the precursor powders of SrFe $_{12}$ O $_{19}$ (a) and BaFe $_{12}$ O $_{19}$ (b), and for the powders of SrFe $_{12}$ O $_{19}$ (c) and BaFe $_{12}$ O $_{19}$ (d) after been calcinated at 800 °C.

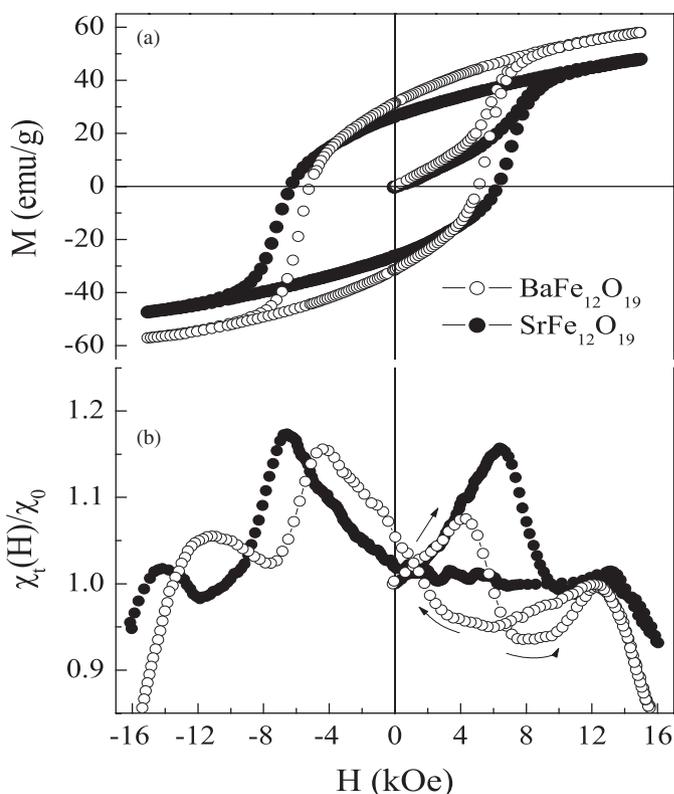


Fig. 3. (a) Room temperature hysteresis loops and (b) transverse susceptibility χ_t vs. applied magnetic field for barium and strontium hexaferrite samples.

field $M_{H=15\text{kOe}}$ obtained from the data for the barium (strontium) hexaferrite was 57.4 emu/g (47.5 emu/g) while the coercive field determined using the same data was 5.13 kOe (6.31 kOe).

The magnetic properties of the powder are in good agreement with a theoretical models developed for uniaxial single-domain particles as discussed next. First, the critical diameter D_{crit} for spherical single-domain particles of $\text{SrFe}_{12}\text{O}_{19}$ and $\text{BaFe}_{12}\text{O}_{19}$ are 940 and 900 nm [11], respectively. Moreover, the theoretical value obtained for the coercive fields at room temperature, based on the Stoner–Wohlfarth model [12], for a system of randomly distributed single-domain particles of $\text{SrFe}_{12}\text{O}_{19}$ and $\text{BaFe}_{12}\text{O}_{19}$, under reverse magnetization and coherent rotation, are 6.7 and 5.9 kOe, respectively. The value of the average size of the particles present in our samples are well below than the theoretical one. Furthermore, the theoretical values for H_c are also slightly larger than those obtained experimentally. Thus, based in these results and assuming that the Stoner–Wohlfarth model applies to our samples, we can infer that the main mechanism responsible for the reversion of the magnetization of the particles is the coherent rotation.

Fig. 3(b) shows dependence of the transverse susceptibility χ_t with the applied magnetic field for the $\text{SrFe}_{12}\text{O}_{19}$ and $\text{BaFe}_{12}\text{O}_{19}$ samples. The virgin curves (increasing the field positively) show two peaks while those obtained diminishing the field show a single peak for positive values of field and two peaks for the negative values of H . Aharoni et al. [13] predicted theoretically that for the χ_t versus H data for a system of randomly distributed single-domain particles, having positive uniaxial anisotropy, one should find singularities located at both the coercive and anisotropy fields. This was firstly confirmed experimentally by Pareti and Turilli [14] on powders of barium hexaferrite. In our samples we also found peaks localized around the coercive fields H_c . We also observed peaks symmetrically localized at ± 11.6 kOe and at ± 13.5 kOe for $\text{BaFe}_{12}\text{O}_{19}$ and $\text{SrFe}_{12}\text{O}_{19}$, respectively, allowing us to infer from this analysis that those could correspond to an average anisotropy field for our samples. Unfortunately, for granular materials the analysis is somewhat more compli-

cated because one needs to deconvolute the anisotropy field distributions, characteristic of granular materials, in order to actually get the anisotropy field.

4. Conclusions

In conclusion, ultrafine particles of $\text{SrFe}_{12}\text{O}_{19}$ and $\text{BaFe}_{12}\text{O}_{19}$, with average particle size close to 50 nm, were successfully prepared by the ICR technique. The magnetization data showed that the powders are mainly composed by single-domain particles. The transverse magnetic susceptibility versus applied magnetic field data reproduced nicely the theoretical prediction made by Aharoni et al. for a system composed of single-domain particles under coherent rotation.

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