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Magnetic Properties of Barium Ferrite Particles with Fe₃O₄ Overcoat

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Abstract. Superparamagnetic Fe₃O₄ fine particles were introduced onto the surface of barium ferrite particles. The method was to coat the barium ferrite particles with a mixed solution of Fe³⁺ and Fe²⁺ first at certain concentrations, followed by addition of NaOH_(aq). The results showed that the coercivity of barium ferrite could be lowered greatly while a high saturation magnetization value was sustained. It indicates that there exists an interaction between barium ferrite and Fe₃O₄ fine particles and this interaction is a matter of interface and may not bear dependency on whether chemical bonding is formed between them.

1. INTRODUCTION

In recent years there has been growing industrial and academic interest in the development of barium ferrite (BF) due to its potential application in high density magnetic recording. For this application, much effort has been paid upon doping Ti, Co, Mn...etc. into BF to reduce its coercivity (H_c), however at the expense of lowering greatly the saturation magnetization (σ_s). Surface coating on BF particles with Fe₃O₄ formed by the precipitation method[1], which has a high σ_s (69 emu/g), is highly potential to reduce H_c . The surface modification of BF particles by the formation of a Fe₃O₄ epitaxial layer has been tried by Kiyama *et al.* and Sadamura *et al.*[2,3] As reported for the modified BF particles, their coercivities decreased and magnetizations increased with the incorporation of Fe₃O₄ layers. In this work, we tried to introduce directly the fine Fe₃O₄ particles onto the surface of the BF particles.

2. EXPERIMENTAL

Barium ferrite particles were firstly prepared by a salt-melt method according to our previous work[4]. They were typically hexagonal platelets with sizes 60-500 nm.

Superparamagnetic Fe₃O₄ fine particles were prepared in sequence by preparing a solution of FeCl₃·6H₂O and FeCl₂·4H₂O at a [Fe³⁺]/[Fe²⁺] molar ratio of 1.98, coprecipitating by adding a NaOH solution with a molar amount equivalent to 4 times that of total cations in the solution, washing with deionized water, filtering and drying at 100°C.

Fe₃O₄ coated BF was prepared by adding BF powders into the solution with the [Fe³⁺]/[Fe²⁺] molar ratio of 1.98, with various concentrations, viz. [Fe³⁺]=2, 5, 7 M, taking BF particles out of the solution by a magnet enclosed by a thin PVC film, dipping the particles in a 2.5 M NaOH_(aq) by taking the magnet away from the film, washing with deionized water, filtering and drying 100°C.

The crystal structure was identified by X-ray diffractometry (XRD) using CuK α radiation. The particle morphology was examined by a transmission electron microscope (TEM). The magnetic properties were measured using a vibrating-sample magnetometer (VSM) with a maximum field of 2 T at room temperature.

3. RESULTS AND DISCUSSION

In Fig. 1, the diffraction patterns show that pure barium ferrite and Fe₃O₄ were obtained. Their magnetic properties are listed in Table 1. It is seen that the Fe₃O₄ particles are superparamagnetic. When these Fe₃O₄ fine particles move close to the

Fig. 1 XRD patterns of barium ferrite (a) and Fe_3O_4 (b)

Fig. 2 The particle morphology of the surface coated BF

surface of BF, they would be magnetized and attracted onto the BF surface under magnetic field of the BF particles. Thus, if the surface of BF is coated with the mixed solution of Fe^{3+} and Fe^{2+} first, after addition of $\text{NaOH}_{(\text{aq})}$, Fe_3O_4 fine particles are then expected to form and adhere onto the surface of BF. With this approach, the BF surface coated with Fe_3O_4 particles were fabricated and their magnetic properties are listed in Table 2. It is seen that the coercivity decreases with coating concentration of the mixed Fe^{3+} and Fe^{2+} solution while, however, the magnetization remains at a high value. It thus indicates that there exists an obvious interaction between the BF and Fe_3O_4 particles thereon. Since there is seldom possibility that strong chemical bonding at the interface between the BF and Fe_3O_4 particles can be formed by the low temperature process we adopted, the lowering of coercivity is a matter of interface interaction which leads to strong magnetic coupling.

Table 1. Magnetic properties of barium ferrite and Fe_3O_4

Materials	σ_s (emu/g)	σ_r (emu/g)	H_c (Oe)
Barium ferrite	70.3	35.3	3400
Fe_3O_4	62.2	0	0

Table 2. Magnetic properties of surface coated barium ferrite

Sample	σ_s (emu/g)	σ_r (emu/g)	H_c (Oe)
$[\text{Fe}^{3+}] = 2 M$	61.7	27.3	2910
$[\text{Fe}^{3+}] = 5 M$	56.8	22.2	2520
$[\text{Fe}^{3+}] = 7 M$	58.9	23.6	1470

The morphology of the surface coated BF with the Fe_3O_4 fine particles is shown in Fig. 2. It can be seen that there is a thin layer of Fe_3O_4 covering the surface of BF.

For the surface coated BF with the solution of $[\text{Fe}^{3+}] = 5 M$, referring to Table 2, its σ_s was 56.8 emu/g and H_c 2520 Oe, while after a heat treatment at 300°C for 5 h its σ_s was measured to increase to 63.5 and H_c remained the same. Since σ_s of the superparamagnetic Fe_3O_4 increased to 69.5 emu/g after the same heat treatment, the increase in σ_s for the surface coated BF may be due to the fact that the amorphous Fe-O or FeOOH phase which is present before the heat treatment but crystallizes after the heat treatment. The heat treatment at 300°C may induce certain degree of chemical reaction at the interface between the BF and Fe_3O_4 particles, however, its coercivity remains the same. This fact depicts that the increase in coercivity caused by the magnetic coupling may not bear dependency on whether chemical bonding is formed.

Acknowledgments

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