Magnetic Properties of Barium Ferrite Particles with Fe3O4 Overcoat
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To cite this version:
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Abstract. Superparamagnetic Fe$_3$O$_4$ 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 Fe$^3+$ and Fe$^2+$ 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 Fe$_3$O$_4$ 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 (Hc), however at the expense of lowering greatly the saturation magnetization (Ms). Surface coating on BF particles with Fe$_3$O$_4$ formed by the precipitation method[1], which has a high Ms (69 emu/g), is highly potential to reduce Hc. The surface modification of BF particles by the formation of a Fe$_3$O$_4$ 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 Fe$_3$O$_4$ layers. In this work, we tried to introduce directly the fine Fe$_3$O$_4$ 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 Fe$_3$O$_4$ fine particles were prepared in sequence by preparing a solution of FeCl$_3$.6H$_2$O and FeCl$_2$.4H$_2$O at a [Fe$^{3+}$]/[Fe$^{2+}$] 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.

Fe$_3$O$_4$ coated BF was prepared by adding BF powders into the solution with the [Fe$^{3+}$]/[Fe$^{2+}$] molar ratio of 1.98, with various concentrations, viz. [Fe$^{3+}$]=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 CuKα 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 Fe$_3$O$_4$ were obtained. Their magnetic properties are listed in Table 1. It is seen that the Fe$_3$O$_4$ particles are superparamagnetic. When these Fe$_3$O$_4$ fine particles move close to the

Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/jp4:19971304
Fig. 1 XRD patterns of barium ferrite (a) and Fe$_3$O$_4$ (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 NaOH$_{(aq)}$, Fe$_3$O$_4$ fine particles are then expected to form and adhere onto the surface of BF. With this approach, the BF surface coated with Fe$_3$O$_4$ 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$_3$O$_4$ particles thereon. Since there is seldom possibility that strong chemical bonding at the interface between the BF and Fe$_3$O$_4$ 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$_3$O$_4$

<table>
<thead>
<tr>
<th>Materials</th>
<th>$\sigma_x$ (emu/g)</th>
<th>$\sigma_z$ (emu/g)</th>
<th>$H_c$ (Oe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium ferrite</td>
<td>70.3</td>
<td>35.3</td>
<td>3400</td>
</tr>
<tr>
<td>Fe$_3$O$_4$</td>
<td>62.2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Magnetic properties of surface coated barium ferrite

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\sigma_x$ (emu/g)</th>
<th>$\sigma_z$ (emu/g)</th>
<th>$H_c$ (Oe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Fe$^{3+}$]=2 M</td>
<td>61.7</td>
<td>27.3</td>
<td>2910</td>
</tr>
<tr>
<td>[Fe$^{3+}$]=5 M</td>
<td>56.8</td>
<td>22.2</td>
<td>2520</td>
</tr>
<tr>
<td>[Fe$^{3+}$]=7 M</td>
<td>58.9</td>
<td>23.6</td>
<td>1470</td>
</tr>
</tbody>
</table>

The morphology of the surface coated BF with the Fe$_3$O$_4$ fine particles is shown in Fig. 2. It can be seen that there is a thin layer of Fe$_3$O$_4$ covering the surface of BF.

For the surface coated BF with the solution of [Fe$^{3+}$]=5 M, referring to Table 2, its $\sigma_x$ was 56.8 emu/g and $H_c$ 2520 Oe, while after a heat treatment at 300°C for 5 h its $\sigma_z$ was measured to increase to 63.5 and $H_c$ remained the same. Since $\sigma_z$ of the superparamagnetic Fe$_3$O$_4$ increased to 69.5 emu/g after the same heat treatment, the increase in $\sigma_z$ 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$_3$O$_4$ 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

This work was sponsored by the National Science Council of the Republic of China under grant NSC 85-2216-E-233-001.

References