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Dependence of the magnetostrictive properties of cobalt ferrite on the initial powder particle size distribution

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Dependence of the magnetostrictive properties of cobalt ferrite on the initial powder particle size distribution

Abstract
The dependence of the magnetostrictive properties of cobalt ferrite on the size distribution of the powder used in deriving the samples from traditional ceramic approach is presented. Sample obtained by combining the smallest and largest particle size distributions gave the highest magnetostriction and strain sensitivity (216 ppm and 1.34 nm/A, respectively), for measurement in parallel direction but the least (66 ppm and 0.38 nm/A respectively) in perpendicular direction. Sample derived from largest particle size distribution gave the least magnetostriction and strain sensitivity (147 ppm and 0.61 nm/A, respectively) in parallel direction but the highest (126 ppm and 0.5 nm/A, respectively) in the perpendicular direction.

Keywords
Ames Laboratory, Magnetostriction, Cobalt, Ferrites, Nanopowders, Ceramics

Disciplines
Ceramic Materials | Electromagnetics and Photonics

Comments
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I. INTRODUCTION

Magnetostrictive materials have potentials for applications in stress/torque sensors development and composite magnetoelectric device fabrication. For applications in chemically or thermally challenging environments, or where it is desirable to avoid losses due to eddy current, oxide based materials are more appropriate. Among the oxides, materials based on cobalt ferrite have both sufficient magnetostrictive amplitude and strain derivative for many applications, considering that 30 ppm obtainable for Ni is sufficient for applications. Cation substitution, high pressure processing and heat treatment have been investigated for optimizing the magnetostrictive properties of cobalt ferrite. It was recently shown, for nanoparticles derived from auto-combustion method, that initial particle sizes affect the magnetostrictive properties of cobalt ferrite. Since most ceramics oxides, such as cobalt ferrite are often fabricated via the traditional ceramic processing technique, it is desirable to investigate the extensibility of the importance of initial particle sizes to micron-size powders often obtained from the traditional ceramic method. In this work, the dependence of the magnetostrictive properties of cobalt ferrite on the distribution of the initial powder particle sizes, derived from the traditional ceramic synthesis, is presented.

II. EXPERIMENTAL DETAILS

Samples were fabricated by the traditional ceramic technique in line with the chemical reaction;

\[ \text{Co}_3\text{O}_4 + 2\text{Fe}_3\text{O}_4 = 3\text{CoFe}_2\text{O}_4. \]  

The mixed oxides were compacted, calcined twice and sintered in air for 24 h at 1350°C for 24 h in an air furnace. To study the microstructure and determine the final compositions of the samples, backscattered electron micrographs were obtained using a scanning electron microscope equipped for energy dispersive x-ray spectroscopy (EDX). Magnetostriiction was measured both in the parallel and perpendicular directions with resistive strain gauges attached onto the samples. The strain sensitivity \( (d\lambda/dH) \) was obtained by differentiating the magnetostriction data as a function of applied magnetic field. Magnetic susceptibility was determined from initial magnetization data obtained using a vibrating sample magnetometer.

III. RESULTS AND DISCUSSION

The XRD pattern in Fig. 1 has only peaks corresponding to the spinel crystal structure indicating that the samples are single phase. A lattice parameter of 8.39 Å was obtained, which is typical of spinel structured materials. Composition determined by EDX is \( \text{Co}_{0.96}\text{Fe}_{2.03}\text{O}_4 \) (Fe:Co ratio of 2.13:1) which indicates that the samples are iron rich. Oxygen is taken to be in the stoichiometric state since EDX is not sufficiently sensitive to determine its concentration in the composition. Table I also shows that the samples are within 68% ± 1.5% of the theoretical density of cobalt ferrite (5259 kg/m³), Fig. 2 shows the backscattered electron micrographs. The uniformity in contrasts obtained for the all the samples further confirms that they are single phase samples.

Fig. 3 shows the magnetostriction plots measured parallel to the direction of the applied field. The inset shows the maximum magnetostriction amplitudes of the samples. It can be seen that magnetostriction increases from sample SP1 until SP5. It decreases beyond SP5 which was the sample derived from largest particle size distribution gave the least magnetostriction and strain sensitivity (126 ppm and 0.61 nm/A, respectively) in parallel direction but the highest (147 ppm and 0.61 nm/A, respectively) in perpendicular direction.

The dependence of the magnetostrictive properties of cobalt ferrite on the size distribution of the powder used in deriving the samples from traditional ceramic approach is presented. Sample obtained by combining the smallest and largest particle size distributions gave the highest magnetostriction and strain sensitivity (216 ppm and 1.34 nm/A, respectively), for measurement in parallel direction but the least (66 ppm and 0.38 nm/A respectively) in perpendicular direction. Sample derived from largest particle size distribution gave the least magnetostriction and strain sensitivity (147 ppm and 0.61 nm/A, respectively) in parallel direction but the highest (126 ppm and 0.5 nm/A, respectively) in the perpendicular direction.

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the previous study on samples derived from nanoparticles that composite of small and large particles enhance magnetostriction amplitude. Comparing SP6 and SP8 derived from smallest particle sizes (<45 μm) and largest particle sizes (>106 μm), respectively, it is obvious that making samples with large particle size powders reduces the magnetostriction amplitude measured along the parallel direction. Since magnetostriction is a magnetomechanical effect, one would expect density, which affects mechanical properties, to also affect magnetostriction. However in this study, it appears that density (Table I) is not the determining factor for magnetostriction amplitude. If it was, SP1 and SP8 with comparable densities would also have similar magnetostriction amplitudes. SP7 derived from an equal amount of all the powders has magnetostriction comparable to SP1, lying between SP6 and SP8.

Fig. 4 shows the magnetostriction plot measured perpendicular to the direction of the applied field. The inset shows the variation of maximum magnetostriction amplitudes of the samples. An opposite trend to that obtained in the parallel direction is observed. SP5 which has the highest magnetostriction in the parallel direction has the least in the perpendicular direction. Similarly, SP8 with the least in the parallel direction has the highest in the perpendicular direction. If 120 ppm is sufficient for an application, the sample SP8 presents a candidate material for use where it is desirable to vary the direction of the applied field while maintaining the magnetostriction amplitude.

FIG. 5 shows that the magnetic field at maximum magnetostriction is independent of the direction of measurement. This property is related to the power required to utilize the full strain amplitude of a magnetostrictive materials. The strain sensitivity (dL/dH) of the samples obtained for both the parallel and perpendicular direction measurements is shown in Fig. 6. Similar trends as in the magnetostriction measurements can be seen. This suggests that a similar

### Table I. Particle size distribution and density of the samples studied. The sample SP7 was made using equal amount of powders from all the particle size distributions.

<table>
<thead>
<tr>
<th>Particle Sizes (μm)</th>
<th>SP1</th>
<th>SP2</th>
<th>SP3</th>
<th>SP4</th>
<th>SP5</th>
<th>SP6</th>
<th>SP7</th>
<th>SP8</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;45</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>45–63</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>100</td>
</tr>
<tr>
<td>64–75</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>100</td>
</tr>
<tr>
<td>75–90</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>100</td>
</tr>
<tr>
<td>&gt;106</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>4167</td>
<td>4308</td>
<td>4231</td>
<td>4273</td>
<td>4255</td>
<td>4312</td>
<td>4252</td>
<td>4163</td>
</tr>
</tbody>
</table>

FIG. 1. X-ray diffraction pattern of the samples. Diffraction pattern was obtained with Mo-Kα radiation; hence, the 2θ positions are different from patterns often reported for analysis with Cu-Kα radiation.

FIG. 2. Backscattered electron micrographs of the samples. Uniform contrasts indicate single phase samples.

FIG. 3. Magnetostriction measured along the direction of the applied magnetic field.
mechanism, other than density, may be responsible for the variations in both properties.

The strain derivative of magnetic field \( \frac{dJ}{dH} \) depends on the coupling between the strain derivative of magnetization \( \frac{d\lambda}{dM} \) and the magnetic susceptibility, \( \frac{dM}{dH} \) (Eq. (2)). From Table II, it appears that the susceptibility is not the dominating factor affecting the magnetostrictive properties. If it was, a correlating trend would be expected. It is therefore likely that \( \frac{d\lambda}{dM} \) is the dominating factor responsible for the observations in the magnetostrictive properties.

\[
\frac{d\lambda}{dH} = \frac{d\lambda}{dM} \frac{dM}{dH}. \tag{2}
\]

IV. CONCLUSION

It has been shown that the particle size distribution of cobalt ferrite is an important factor in controlling the magnetostrictive properties. It is hypothesized that the strain derivative of magnetization \( \frac{d\lambda}{dM} \) may have greater effect on the observed variation of magnetostrictive properties than does density.

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