Magnetostriiction in Nickel Ferrite and Cobalt–Nickel Ferrite

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The magnetostriiction constants $\lambda_{99}$ and $\lambda_{11}$ for nickel ferrite have been measured using a ferromagnetic resonance technique which also permits measurements of linewidth, $g$ factor, and anisotropy on the same sample. Our measurements show that all of these parameters are essentially temperature independent from 4° to 300°K in contrast to the behavior of other ferrites. The magnetostriiction results are: $\lambda_{99} = -46 \times 10^{-6}$, $\lambda_{11} = -22 \times 10^{-6}$ at room temperature with less than a 20% variation from these values down to 4°K. The temperature independence of the linewidth and its magnitude (~20 Oe) both indicate an absence of the ferrous ions which have complicated measurements by some other investigators. Measurements have also been made of the magnetostriiction of $\text{Co}_8\text{Ni}_4\text{Fe}_2\text{O}_8$ over the range 100° to 300°K. At room temperature both $\lambda_{99}$ and $\lambda_{11}$ have approximately the same values as in NiFe$_2$O$_4$, but at lower temperatures the cobalt contribution causes $|\lambda_{99}|$ to increase sharply while $|\lambda_{11}|$ is relatively unaffected.

This behavior is qualitatively in agreement with a theory by Słonczewski for the similar problem of Co$^{2+}$ in magnetite. The sign of $\lambda_{11}$, however, is different in the two materials. Linewidth in the three principal directions in $\text{Co}_8\text{Ni}_4\text{Fe}_2\text{O}_8$ has also been measured.

SATURATION magnetostriiction has been measured on samples of nickel ferrite (NiFe$_2$O$_4$) and cobalt doped ferrite (Co$_8$Ni$_4$Fe$_2$O$_8$) by means of a ferromagnetic resonance technique. On the same samples conventional resonance measurements have been made of linewidth, anisotropy, and $g$ factor. The nickel ferrite has been measured over the range 4° to 300°K and the nickel–cobalt ferrite over a more limited range because large linewidths prevent complete measurements at low temperatures. All measurements were made at approximately 16 Gc/sec.

NICKEL FERRITE

The experimental data on nickel ferrite is summarized in Table I. Measurements at intermediate temperatures confirm that the flat temperature behavior indicated by these three points does exist throughout the 4° to 300°K range. The only previous measurement of magnetostriiction in single-crystal nickel ferrite was at room temperature by Bozorth, Tilden, and Williams.

Although our sample was not analyzed chemically, we take the temperature independence of the linewidth as evidence of a very low ferrous ion content. This conclusion is based on the relationship between linewidth behavior and ferrous ion content first demonstrated by Yager, Galt, and Merritt. Our experience with the oxides indicates that surface effects are not important in determining the linewidth of our nickel ferrite sample. Our sample also seems to be free of some other possible causes of line broadening discussed by the Sekizawas since we measure a linewidth as low as that of their best sample. The fact that the Sekizawas and also Miyamoto et al. measure approximately the same linewidth as we do indicates that this value is probably the intrinsic width of the material.

The temperature independence of the linewidth suggests that it is due to a two-magnon process. However, it is difficult to hypothesize a scattering mechanism in nickel ferrite which gives the correct magnitude for this width. Thus the source of the intrinsic linewidth in this material is still uncertain.

Tsuya has calculated the various possible contributions to the magnetostriiction of nickel ferrite. His results for the dipole–dipole and single ion Ni$^{2+}$ contributions are given in Table II in terms of the magnetoelastic constants per molecule $b'_1$ and $b'_2$. We have modified his Ni$^{2+}$ contribution to conform to our

<table>
<thead>
<tr>
<th>Table I. Anisotropy, g factor, magnetostriiction, linewidth, and magnetization for NiFe$_2$O$_4$ (magnetization values are from Ref. 4).</th>
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<tbody>
<tr>
<td>4.2°K</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>$K_{1}/M$ (Oe)</td>
</tr>
<tr>
<td>$K_{2}/M$ (Oe)</td>
</tr>
<tr>
<td>$g$</td>
</tr>
<tr>
<td>$10^{6}K_{11}/M$</td>
</tr>
<tr>
<td>$10^{5}K_{11}/M$</td>
</tr>
<tr>
<td>$\Delta H_{11}/M$</td>
</tr>
<tr>
<td>$\Delta H_{11}/M$</td>
</tr>
<tr>
<td>$M$ (G)</td>
</tr>
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Table II. Possible contributions to the magnetoelastic coupling in NiFe₂O₄ compared with the experimentally observed value at 4 K.

<table>
<thead>
<tr>
<th></th>
<th>( b' ) (cm(^{-1}))</th>
<th>( b'' ) (cm(^{-1}))</th>
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<tbody>
<tr>
<td>Ni(^{2+})</td>
<td>+35</td>
<td>-6</td>
</tr>
<tr>
<td>Dipole-dipole</td>
<td>-10</td>
<td>+14</td>
</tr>
<tr>
<td>Fe(^{3+}) on B site</td>
<td>+51</td>
<td>-10</td>
</tr>
<tr>
<td>Fe(^{3+}) on A site</td>
<td>-62</td>
<td>+19</td>
</tr>
<tr>
<td>Total</td>
<td>+14</td>
<td>+17</td>
</tr>
<tr>
<td>Experimental value</td>
<td>+32.5</td>
<td>+21</td>
</tr>
</tbody>
</table>

measured g factor and have assumed a spin Hamiltonian \( D \) of \( \approx 1 \) cm\(^{-1}\). It is interesting to note that the Ni\(^{2+}\) ion apparently contributes to the magnetostriction although not to the anisotropy. The lack of a Ni\(^{2+}\) anisotropy contribution is predicted by theory\(^a\) and is also indicated by a comparison of the anisotropy in nickel ferrite with that of lithium ferrite\(^b\) whose magnetic behavior is due entirely to Fe\(^{3+}\).

Because of the difficulties involved in trying to predict the Fe\(^{3+}\) magnetostriction contribution theoretically, we list in Table II values determined from experiment instead of theory. The Fe\(^{3+}\) B-site contribution is derived from Feher\(^a\) ESR measurements of Fe\(^{3+}\) impurities on an octahedral site in MgO. In the absence of any direct experimental data, we deduce the A-site Fe\(^{3+}\) contribution using Feher's data and the magnetoelastic constants\(^b\) of lithium ferrite. Considering the uncertainties in the four initial entries in Table II, the totals are in fair agreement with the experimental values.

**COBALT-DOPED NICKEL FERRITE**

Figure 1(a) shows the magnetostriction vs temperature for our cobalt-doped nickel ferrite sample whose nominal composition is Co\(_{0.96}\)Ni\(_{0.04}\)Fe\(_2\)O\(_4\). Comparison of our \( K_1 \) and \( K_2 \) results with Miyamoto \etal\(^c\)'s chemically analyzed samples indicates the actual composition to be closer to Co\(_{0.98}\)Ni\(_{0.02}\)Fe\(_2\)O\(_4\).

Although no detailed theory exists for the magnetostriction of Co\(_{x}\)Ni\(_{1-x}\)Fe\(_2\)O\(_4\), qualitative comparisons are possible with Slonczewski's\(^d\) theory for cobalt-doped magnetite. Comparisons are only qualitative because the Co\(^{3+}\) ion in NiFe\(_2\)O\(_4\) sees a lower symmetry crystal field than the trigonal field existing in magnetite. This lower symmetry decreases the magnetostrictive effect. Slonczewski's theory predicts for both \( \lambda_{\text{Bo}} \) and \( \lambda_{\text{Ai}} \) an increase with lowering temperature such as that displayed by our \( \lambda_{\text{AI}} \) data. It also predicts a steeper temperature dependence for \( \lambda_{\text{AI}} \) than \( \lambda_{\text{Bo}} \) in agreement with our observations. Although the magnitude of \( \lambda_{\text{AI}} \) agrees qualitatively with his Co\(_{x}\)Fe\(_{2-x}\)O\(_4\) theory, it is of the opposite sign. However, in order to obtain agreement between theory and experiment in Co\(_{x}\)Fe\(_{2-x}\)O\(_4\), he had to assume for one constant the opposite sign from that given by measurements in CoO.

The linewidths \( \Delta H \) in the [100], [110], and [111] directions are shown in Fig. 1(c). The dashed line indicates the region where the linewidth was too large to be measured accurately. The lowest value of linewidth measured in this material was 19.2 Oe at 4.2°K. The room-temperature linewidth in cobalt-doped ferrites is probably due to a \( k=0 \) to \( k\neq 0 \) scattering process\(^e\) which would result in an isotropic linewidth of approximately the observed magnitude. An explanation for the anisotropic low-temperature behavior has been given by Teale and Clarke\(^f\) who suggest that the Co\(^{3+}\) linewidth contribution can perhaps be explained by an adaptation of the existing theory for Yb\(^{3+}\) in garnets.

Figure 1(b) shows the shift in field for resonance \( \delta H \) observed upon applying a stress in the [110] direction. These are the shift measurements from which the \( \chi' \)'s are calculated.\(^1\) The correlation between the \( \Delta H_{110} \) and \( \delta H_{110} \) behavior suggests that the low-temperature increase in both is due to the same coupling to the lattice. The quantities \( \delta H_{110} \) and \( \Delta H_{110} \) are linearly related throughout the temperature range \( \approx 80° \) to \( 300°\)K in which accurate measurements are possible.
