Determination of anisotropy field in polycrystalline lithium ferrites from FMR linewidths

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A technique for separating anisotropy and porosity induced FMR line-broadening contributions in narrow linewidth polycrystals has been extended to large linewidth lithium ferrite materials. The FMR linewidth is measured versus frequency and temperature T. Since the porosity contribution is proportional to the magnetization $4\pi M_s$, and the anisotropy field H_a falls off much faster at high T than does $4\pi M_s$, the two contributions to the linebroadening can be separated. Three samples were studied: Li-ferrite with and without cobalt addition (0.01 Co atoms/formula unit), and a Li-ferrite with 0.01 Co and 0.26 Ti at./f.u. The anisotropy field for unsubstituted Li-ferrite was found to decrease monotonically with T with $H_a \approx 350$ Oe at 25 °C, in agreement with single crystal data. Cobalt addition was found to decrease the room temperature H_a in the Li-ferrite without titanium but not in the Li-Ti-ferrite. This agrees with previous observations of Ti decreasing the effectiveness of Co in reducing the anisotropy.

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INTRODUCTION

Direct data on the anisotropy field H_a are generally unavailable for polycrystalline lithium ferrite with substitutions because it is difficult to grow anything but lightly doped single crystals. A technique for determining H_a from polycrystals is therefore highly desirable. Such a technique for separating the porosity and anisotropy induced FMR linebroadening contributions in narrow linewidth polycrystals has been developed by Röschmann (1). The FMR linewidth ΔH is first measured vs. frequency and temperature. This polycrystalline linewidth is the sum of three contributions.

$$\Delta H = \Delta H_s + \Delta H_p + \Delta H_a \qquad (1)$$

In Eq. (1) ΔH_s is the single crystal or intrinsic linewidth, and ΔH_p and ΔH_a are the porosity and anisotropy induced linebroadening contributions, respectively. The intrinsic linewidth can be determined from single crystal or high field effective linewidth data. The porosity linewidth vs. frequency is determined from data at high temperature, where H_a and ΔH_a are negligible. Since ΔH_p is proportional to the saturation induction $4\pi M_s$, $4\pi M_s$ vs. temperature can then be used to subtract out ΔH_p over the lower temperature range where anisotropy is not negligible, and hence obtain ΔH_a vs. frequency and temperature.

The anisotropy field is then determined from the anisotropy linewidth ΔH_a and Schlömann's two-magnon anisotropy linebroadening equations (2),

$$\Delta H_a = (2.07\, H_a^2/4\pi M_s) G(\Omega, \Omega_i) \qquad (2)$$

and

$$G(\Omega,\Omega_i) = \frac{19}{40\sqrt{3}} \frac{\Omega_i^2 + (2/19)\Omega\Omega_i + \Omega^2}{[\Omega_i^3(\Omega_i^2 + \Omega_i - \Omega^2)]^{1/2}} \,. \qquad (3)$$

In Eqs. (2) and (3), Ω_i is the static internal resonance field, normalized to the saturation induction, and Ω is the resonance frequency normalized to $\gamma 4\pi M_s$, where γ is the gyromagnetic ratio 2.799 MHz/Oe. The function G accounts for both the spectral distribution of the crystalline anisotropy fields and the varying density of available degenerate spin-wave states. Röschmann has determined H_a in polycrystalline YIG by the above technique and obtained excellent agreement with single crystal data.

EXPERIMENT

This technique has now been extended to large linewidth lithium ferrite materials with room temperature FMR linewidths of 300–450 Oe. This extension is significant because of the large porosity linebroadening and large anisotropy fields. The normalized porosity linebroadening $\Delta H_p/4\pi M_s$ in the investigated samples ranged from 0.05 to 0.10, which is an order of magnitude larger than in previous investigations. The normalized anisotropy field $H_a/4\pi M_s$ ranged from 0.09 to 0.17. Equations (2) and (3) were derived using a model which assumed $H_a \ll 4\pi M_s$. A check is thus made on the validity of this anisotropy linebroadening model for $H_a/4\pi M_s$ values in this range.

The samples investigated were "pure" lithium ferrite (LF), lithium ferrite substituted with 0.01 Cobalt atoms/formula unit (LCF), and lithium ferrite substituted with 0.01 Co and 0.26 Titanium/f.u. (LTCF). All samples had 0.1 Manganese/f.u. Manganese at this level is used to suppress Fe^{+2} ion conductivity. It has a negligible effect on the anisotropy (3). Because of the large porosity and anisotropy linewidth contributions, the small ΔH_s values (on the order of a few Oe from single crystal (8) and effective linewidth data) may be neglected.

Single crystal data for pure lithium ferrite can be used to check the accuracy of the anisotropy field obtained for sample LF. Furthermore, the Co doping level in LCF should cause the room temperature H_a to decrease (4,5). Titanium addition is believed to nullify the effect of Co on the anisotropy field (4,6,7). Sample LTCF should therefore not exhibit the reduction in H_a seen in LCF.

RESULTS

Figure 1 shows FMR linewidth vs. frequency and temperature for sample LF, plotted in normalized units. The curves converge on the 375°C curve as temperature increases. This is indicative of the decrease in the anisotropy linebroadening contribution with increasing T. The 375°C curve can be taken as the porosity linebroadening contribution. Figure 2 shows the anisotropy linebroadening contribution, obtained by subtracting the porosity linebroadening contribution from the linewidth over the entire range of temperature. The anisotropy field is computed using this anisotropy linebroadening contribution, $4\pi M_s$ vs. temperature, and Eqs. (2) and (3). The anisotropy field results for LF are shown in Fig. 3, along with results from samples LCF and LTCF.

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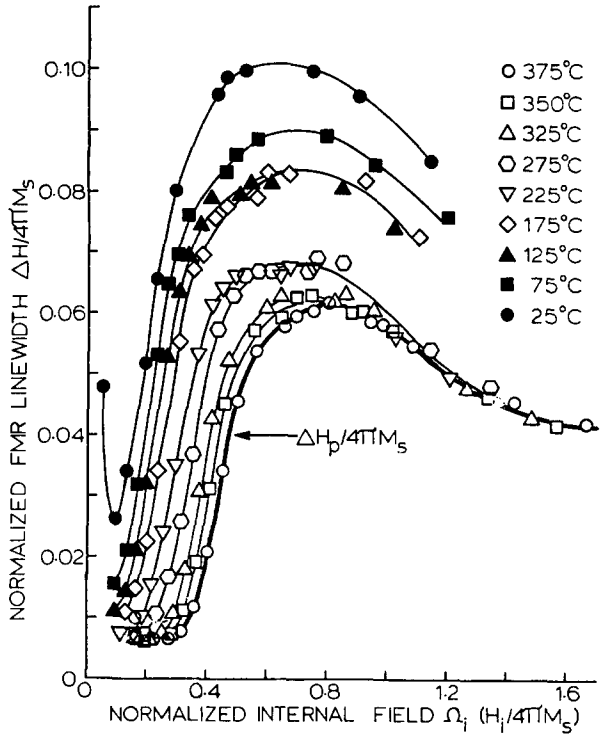

Fig. 1. Normalized FMR linewidth vs. normalized static internal field ($\Omega_i = H_i/4\pi M_S$) for sample LF at different temperatures.

DISCUSSION

From measurements of the anisotropy constants (k_1,K_2) in unsubstituted single crystal lithium ferrite, H_a is 375 Oe at 25°C (3) and decreases monotonically with temperature. The anisotropy field results for sample LF agree well with these predictions. Sample LCF displays the expected drop in room temperature H_a due to cobalt. The anisotropy field results for LMTF are very close to those of LF, which provides an indication that the titanium additions are indeed nullifying the effect of Co on H_a.

Schlömann developed anisotropy linebroadening models for two cases (10,11): $H_a >> 4\pi M_S$ (independent

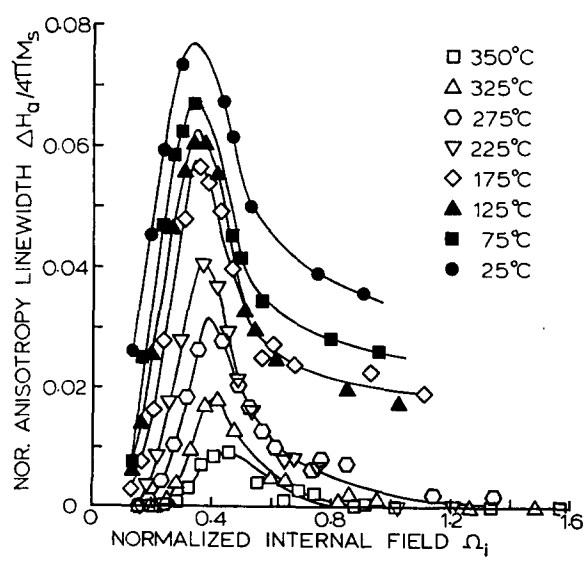

Fig. 2. Normalized anisotropy broadened linewidth vs. normalized static internal field for sample LF at different temperatures.

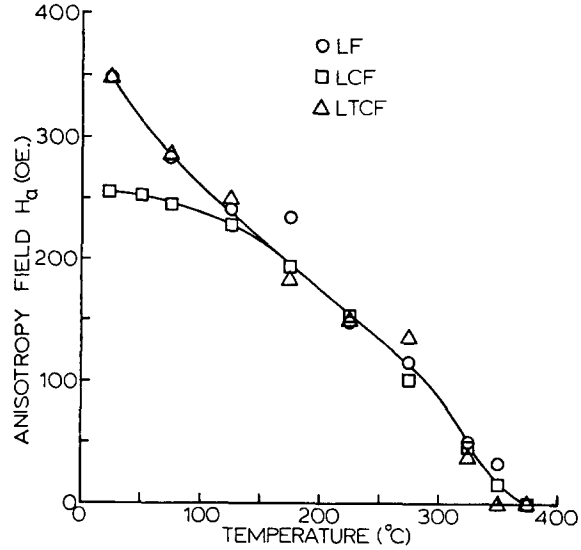

Fig. 3. Anisotropy field H_a vs. temperature for samples LF, LCF, and LTCF.

grain approach) and $H_a << 4\pi M_S$ (spin wave approach). The spin wave approach, from which Eqs. (2) and (3) arise, assumes dipolar forces to be dominant. Crystalline anisotropy is treated as a weak coupling mechanism between the uniform precession mode and low wavenumber spin waves. In the investigated samples, $H_a/4\pi M_S$ ranged from about 0.1 to 0.2. Figure 4 compares the anisotropy linebroadening contribution of sample LF with Eq. (2). The agreement is good for temperatures below 225°C, but deteriorates at higher temperatures. The difficulty in detecting small ΔH_a contributions on top of large ΔH_p contributions at these temperatures could easily account for the discrepancy. These $H_a/4\pi M_S$ ratios therefore appear to remain within the useful range of the spin wave approach. The large porosity linebroadening in these samples appears to have no significant effect on the technique other than

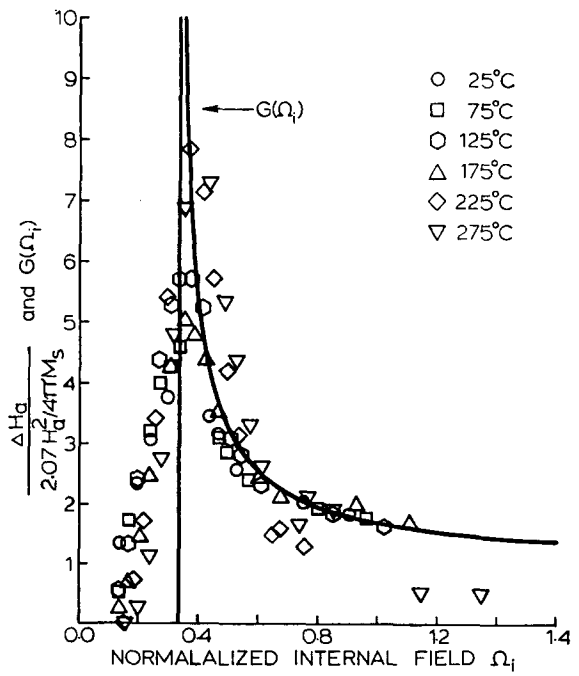

Fig. 4. Comparison of anisotropy broadened linewidth to Schlömann's theory. Normalized anisotropy broadened linewidth divided by the theoretical inhomogeneity parameter, and G, vs. normalized static internal field.

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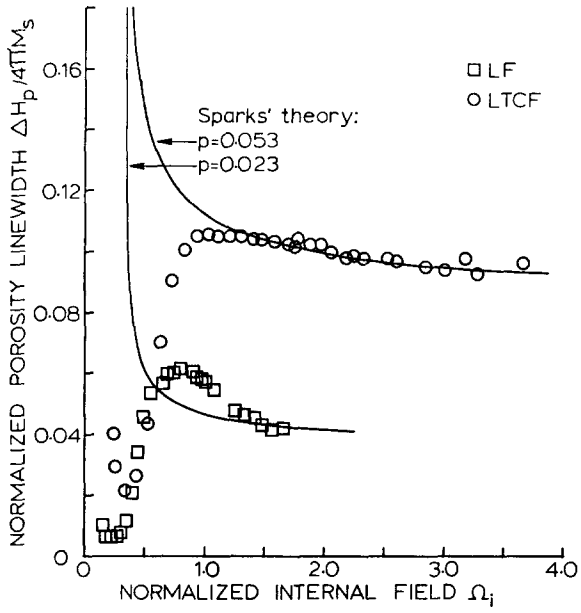

Fig. 5. Normalized porosity broadened linewidth vs. normalized static internal field for samples LF and LTCF. Sparks' porosity broadening theory is also plotted. The porosity, p, is the pore volume to sample volume ratio.

a decreased precision in the ΔH_a determination, as mentioned above.

Figure 5 shows the porosity linebroadening contributions for LF and LTCF. They are compared to a porosity linebroadening expression developed by Sparks (12) which is based on a spherical pore scattering model. Agreement with sample LF was poor. Sample LTCF agrees for large Ω_i only, which is similar to observations of Röschmann in narrow linewidth materials. The agreement for large Ω_i is somewhat unsatisfactory, however, as the theoretical expression was empirically modified (12) to fit in this region. The porosity linebroadening will be considered in detail in a future report.

CONCLUSIONS

Röschmann's technique for FMR determination of anisotropy and porosity linebroadening has been extended to broadline polycrystalline ferrites and gives satisfactory results. Experimentally determined H_a values agree with predicted results in cases where single crystal data are available. The data indicate that titanium substitutions decrease the effectiveness of cobalt in reducing anisotropy.

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REFERENCES

1. P. Röschmann, IEEE Trans. Mag. 11, 1247 (1975).
2. E. Schlömann, J. Phys. Chem. Solids 6, 242 (1958).
3. H. J. Van Hook and G. F. Dionne, AIP Conf. Proc. No. 24, 487 (1974).
4. S. K. Banerjee, P. D. Baba, B. J. Evans, and S. S. Hafner, J. Phys. Suppl. (Paris) 32, C1-145 (1971).
5. M. A. Stel'mashenko, Sov. Phys.-Solid State 9, 1137 (1967).
6. H. J. Van Hook and J. J. Green, Air Force Materials Laboratory, Air Force Systems Command, Tech. Rept. AFML-TR-74-146 (1974).
7. P. D. Baba and S. K. Banerjee, MIT Lincoln Laboratory Tech. Rept. ESD-TR-68-251, August 1968.
8. E. G. Spencer, D. A. Lepore, and J. W. Nielsen, J. Appl. Phys. 39, 732 (1968).
9. V. J. Folen, J. Appl. Phys. 31S, 166S (1960).
10. E. Schlömann, J. Phys. Chem. Solids 6, 257 (1958).
11. E. Schlömann, J. Phys. Radium 20, 32 (1959).
12. M. Sparks, J. Appl. Phys. 35, 1570 (1965).

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