MICROWAVE RELAXATION PROPERTIES OF SUBSTITUTED LITHIUM FERRITE

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Abstract - The effect of Co, Mn, Ti, and Al substitutions on two important microwave relaxation parameters, the spin-wave linewidth ΔH_k and the high field effective linewidth ΔH_{eff}, for lithium ferrite, $Li_{0.5}Fe_{2.5}O_4$, has been examined. Cobalt tends to increase both linewidths, while Mn tends to decrease them. The quantitative dependences, however, indicate that an optimum Mn level, at about 0.5 at./F.U., serves to maximize the ratio $\Delta H_k/\Delta H_{eff}$. There is no marked change in the effect of cobalt on either linewidth parameter as Ti and/or Al substitutions are made to reduce the saturation induction. However, Ti substitutions are found to substantially decrease ΔH_k, while causing a moderate (factor of two) increase in ΔH_{eff}.

INTRODUCTION

Lithium ferrite materials with Co, Mn, Ti, and Al substitutions are of technological importance for use in radar. The substitutional levels which optimize device performance have generally been determined empirically from data on switching properties, insertion loss, device degradation at high power, etc., depending on the particular device of interest.

The purpose of this work is to report on the effect of the above substitutions on two fundamental microwave relaxation parameters, the spin-wave linewidth and the high field effective linewidth. The spin-wave linewidth ΔH_k, derived from observation of the critical microwave field amplitude for the onset of spin-wave instability processes and an abrupt increase in ferrite loss, is a quantitative indicator of the peak power capability of the ferrite.[1] The high field effective linewidth ΔH_{eff}, derived from measurements of the microwave susceptibility under field bias conditions very far from ferromagnetic resonance, is a quantitative indicator of the insertion loss for the material in nonresonant device applications (such as latching phase shifters, for example).[2] Data on ΔH_k were obtained by parallel pumping at 8.9 GHz. Data on ΔH_{eff} were obtained at 9.8 GHz. All results are for ambient room temperature.

COBALT AND MANGANESE SUBSTITUTIONS

The effect of various substitutions in Li-ferrite have been reviewed recently[3] and only the relevant highlights are summarized here. Cobalt is considered, within the framework of the single ion theory, as entering into B-sites as Co^{2+} and making a positive contribution to the magnetocrystalline anisotropy constant K_1. This can serve to compensate the negative K_1 intrinsic to pure Li-ferrite. A related compensation in magnetostriction is also expected. Very small amounts are needed to accomplish these effects in pure lithium ferrite. Cobalt also contributes to the impurity or temperature peak relaxation processes, qualitatively similar to the effect of residual Fe^{2+} in ferrites or rare earths in garnets.

Small amounts of Mn^{3+} are added to microwave Li-ferrite to oxidize any residual Fe^{2+} which is inevitably present and achieve higher resistivities as well as a reduced temperature peak linewidth. Both contribute to a reduced overall linewidth.

Both substitutions are often present in materials engineered to specific device applications. The effects of cobalt and manganese on the spinwave linewidth and effective linewidth are shown in Figs. 1 and 2, respectively. As discussed above, Co tends to increase the linewidths while Mn tends to decrease the linewidths. The interesting feature is that, while the effect of Mn on ΔH_k is gradual and more or less linear, the effect of Mn on ΔH_{eff} is rather abrupt with most of the desirable reduction in ΔH_{eff} occurring for 0.05 Mn at./F.U. Thus, it appears that the

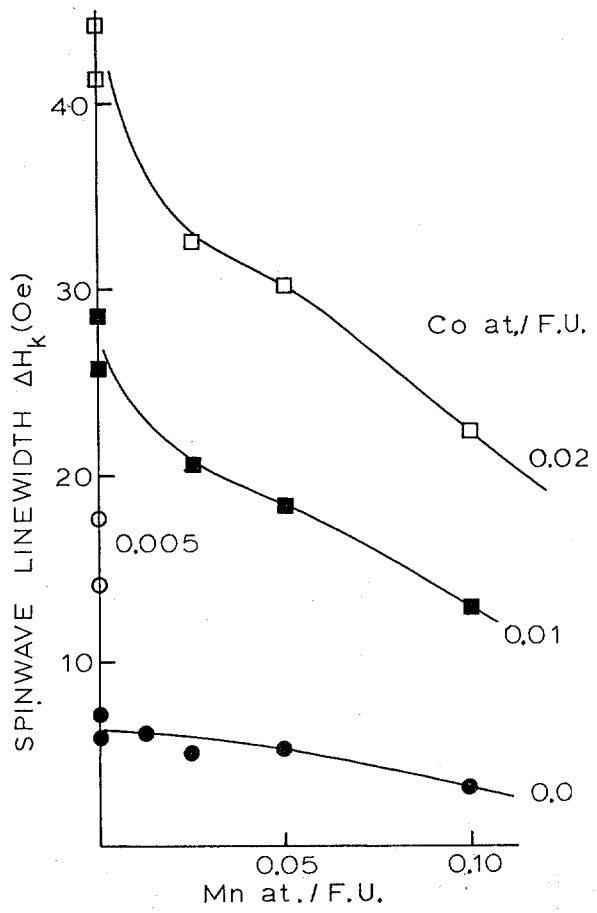

Fig. 1. Spinwave linewidth in Li-ferrite with cobalt and manganese substitutions.

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highest ratio of $\Delta H_k/\Delta H_{eff}$, which is desirable from a device point of view, occurs for 0.05 at./F.U. The abnormally low ΔH_{eff} for the pure Li-ferrite is clearly inconsistent with the other data in Fig. 2 and probably the result of the fortuitous absence of Fe^{2+}.

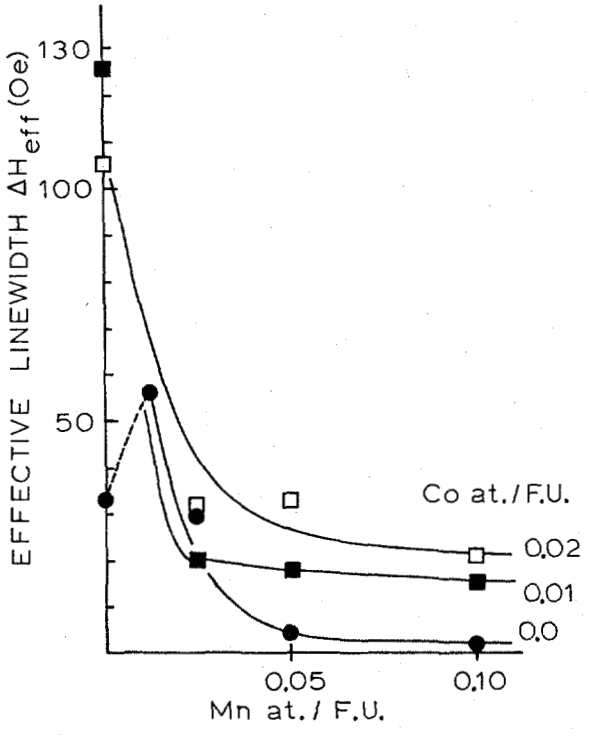

Fig. 2. Effective linewidth in Li-ferrite with cobalt and magnanese substitutions.

TITANIUM SUBSTITUTIONS

Titanium is often added to Li-ferrite to reduce the saturation induction $4\pi M_o$ and thereby obtain a material suitable for operation at the lower microwave frequencies without problems due to low field loss in the remanent state. An assumed site distribution of

$$(Li^{1+}_{0.5x}Fe^{3+}_{1-0.5x})_A[Li^{1+}_{0.5}Fe^{3+}_{1.5-x}Ti^{4+}_{x}]_B O_4$$

is in reasonable agreement with experimental magnetization data up to $x \simeq 1.$[4,5]

Data on the spin-wave linewidth and effective linewidth as a function of Ti substitution are shown in Fig. 3. All samples have 0.1 at.Mn/F.U. It is seen that titanium causes a substitutional reduction in ΔH_k, while ΔH_{eff} appears to increase somewhat below $x \sim 0.25$ and then level off. Because of the low saturation inductions for large x, accurate ΔH_{eff} data could not be obtained. These data indicate that the ratio $\Delta H_k/\Delta H_{eff}$ decreases by a factor of about 6 from x = 0 to x = 0.7, for Li-ferrite with only titanium substitutions.

This decrease does not indicate a corresponding factor of six decrease in the ratio of peak power to loss for a particular device application, however, because the peak power capability also depends on frequency and $4\pi M_o$, as does the actual insertion loss. These dependences must be taken into account in estimating the change in device performance due to the variations in Fig. 3.

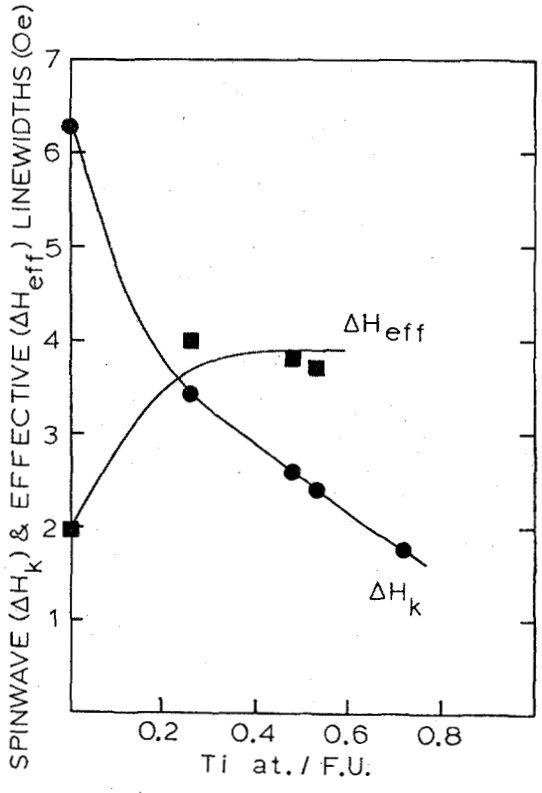

Fig. 3. Spinwave and effective linewidths in Ti substituted Li ferrite.

TITANIUM/ALUMINUM AND COBALT SUBSTITUTIONS

One important problem in Ti-substituted Li-ferrite has been the diminished effectiveness of cobalt in improving loop properties for device materials. The implication is that large Ti additions, which serve to reduce $4\pi M_o$ as noted above, also render the cobalt less effective in compensating the crystalline anisotropy and magnetostriction. The objective of the linewidth measurements on such materials was to see if titanium and related substitutions had any effect on the microwave relaxation processes due to cobalt.

Data on spinwave linewidth and effective linewidth are shown in Figs. 4 and 5, respectively. The compositions corresponding to the plotted symbols are given in the Fig. 4 inset. The trend for ΔH_k is clearly evident in the linear increase in spinwave linewidth with cobalt. For the case of no titanium the increase is about 10 Oe per 0.01 Co atom/F.U. The addition of titanium reduced the increase to about 6 Oe per 0.01 Co atom/F.U. It appears, therefore, that there is a moderate diminution in the effect of cobalt on magnetic properties when diamagnetic substitutions are made in the B-sublattice. It is noteworthy that the data for 0.26 Ti at./F.U., 0.53 Ti at./F.U., and 0.25 Ti; 0.30 Al at./F.U., all lie essentially on the same curve.

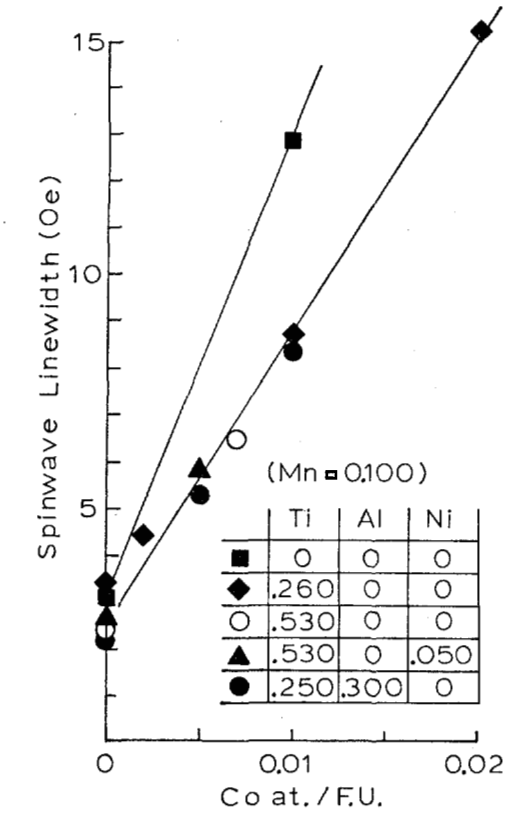

Fig. 4. Spinwave linewidth in Li-Ti and Li-Ti-Al ferrites as a function of cobalt substitution.

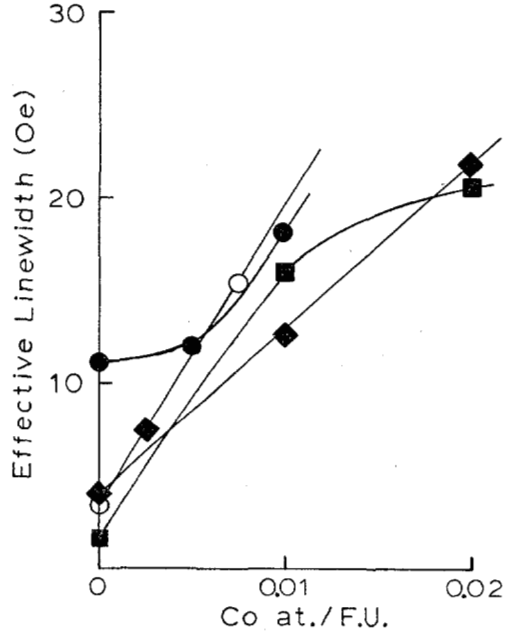

Fig. 5. Effective linewidth in Li-Ti and Li-Ti-Al ferrites as a function of cobalt substitution.

The effective linewidth data in Fig. 5 are less definitive, primarily due to the difficulty in obtaining accurate high field ΔH_{eff} determinations in low $4\pi M_o$, large linewidth ferrites. About all that can be said here is that ΔH_{eff} is increased by the addition of cobalt at about 10 Oe per 0.01 Co at./F.U., more or less independent of the amount of the diamagnetic species on the B-sublattice.

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