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Influence of Microwave Dielectric Properties on the Effective Linewidth in Ferrites

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A series of measurements of the effective linewidth in single-crystal YIG films on GGG and polycrystalline LiTi-ferrite with Mn additions indicate that field-dependent dielectric losses can often obscure the actual magnetic losses and the corresponding effective linewidth. For the LiTiMn-ferrite system, the data indicate that it is the low-field effective linewidth, rather than the high-field effective linewidth which is a measure of the intrinsic magnetic losses of the material.

The effective linewidth method, originally suggested by Motizuki et al.[1] and developed experimentally by Kohane and Schlömann,[2] Vrehen,[3] and Patton and Kohane,[4] has been used to study two-magnon relaxation as well as intrinsic losses in polycrystalline ferrites.[3,5,6] The "intrinsic" losses, so-called because the measurements are designed to exclude two-magnon scattering contributions, were generally obtained from data at high field, sufficient to shift the spin-wave manifold well above the excitation frequency. Low-field data, with the low wave number portion of the spin-wave band below the excitation frequency, gave effective linewidth ΔH_{eff} values which were about the same or larger than the high-field values for fine-grained ferrites, depending on grain size. These results generally supported the assumption that the high-field ΔH_{eff} was the appropriate "intrinsic" magnetic-loss parameter.

However, there have been some problems with high-field effective linewidth data which run counter to the above "intrinsic" label. In some cases, the high-field ΔH_{eff} is clearly larger than the low-field values. This is inconsistent with two-magnon considerations. In addition, the high-field ΔH_{eff} is often found to be an increasing function of dc magnetic field. The aim of the present work was to investigate the still-ambiguous origins of the high- and low-field effective linewidth.

Experiment

The experimental procedure was essentially the same as described in Ref. 4. The samples were placed at the center of a cylindrical TE_{011} microwave cavity. Cavity Q and frequency measurements vs applied dc magnetic field

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were used to determine the complex microwave susceptibility and the effective linewidth vs field.

Measurements were made on two types of ferrite materials, liquid-phase epitaxy yttrium iron garnet (YIG) thin films on gadolinium garnet (GGG) substrates and polycrystalline LiTi-ferrite with Mn additions. These particular materials were chosen for several reasons. The YIG film on GGG was thought to be interesting because of the significant and field-dependent dielectric losses for the GGG.[7] The LiTi-ferrite with Mn is known to have both magnetic and dielectric losses which *decrease* as the Mn content increases. For the films, the analysis of Ref. 4 was modified somewhat to properly account for the thin-film geometry.

Results

The results for both types of materials showed the importance of dielectric losses in general and field-dependent dielectric losses in particular when determining effective linewidths. The YIG results in Fig. 1 illustrate this point rather dramatically. If one ignores the substrate influence and assumes that all of the changes in cavity parameters with field are magnetic in nature, one obtains an effective linewidth for the YIG as shown by the solid points and connecting line. One sees a minimum in the vicinity of the ferromagnetic resonance (FMR) field (≈2.8 kOe) but extremely large ΔH_{eff} values at both

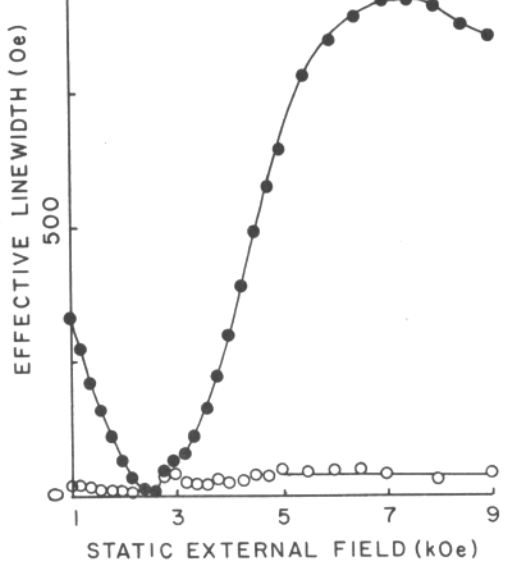

Fig. 1. Effective linewidth vs static external field for an in-plane magnetized YIG film on GGG. The results indicated by the solid points are based on the assumption that all of the losses are magnetic and occur in the YIG film. The data shown by the open circles take the GGG losses into account.

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low and high fields, in contrast with the expected value of about 0.5 Oe at all fields.

It is clear that this apparent effective linewidth cannot represent the losses in the YIG but includes the contribution of the GGG substrate dielectric losses to the change in cavity parameters with field. By measuring the field dependences of these parameters for the GGG only, after carefully removing the film by polishing, it was possible to infer the effect of the YIG alone and to extract the YIG-film ΔH_{eff} from the data. These results are shown by the open circles in Fig. 1. We see that the "true" YIG ΔH_{eff} is much smaller and shows a small bump, presumably due to two-magnon losses, in the vicinity of FMR. More importantly, for this discussion, we see that the flat ΔH_{eff} at low field is lower than the effective linewidth at high field. This may imply, as will be discussed shortly in connection with the LiTiMn-ferrite results, that field-dependent dielectric losses are also operative in the YIG itself.

Similar measurements were made on a series of conventionally prepared polycrystalline LiTi-ferrite materials with 0–0.1 Mn at.%/formula unit. Manganese is generally added to Li-ferrite compositions to convert residual Fe^{2+} to Fe^{3+}. In principle, this reduces both the magnetic and the dielectric losses associated with electron hopping between equivalent-site Fe^{2+} and Fe^{3+} ions. The magnetic-loss reduction would be expected to show up as a decrease in *both* the high-field and low-field ΔH_{eff} linewidths with Mn additions. The dielectric loss reduction, assuming a dielectric loss which increases with field, would affect only the high-field ΔH_{eff}.

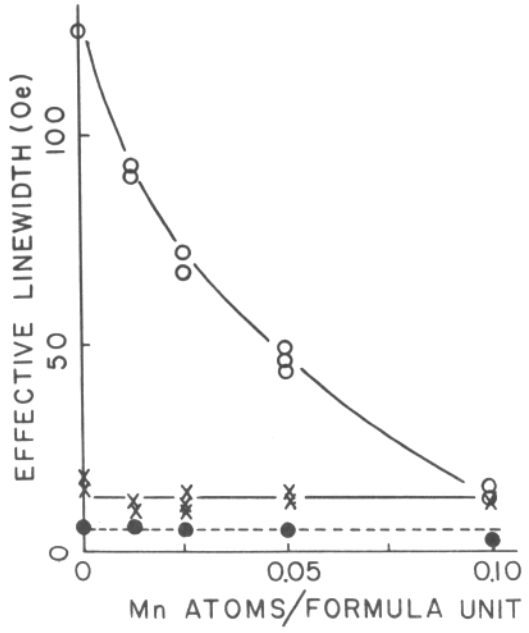

Fig. 2. Low- and high-field effective linewidth for LiTiMn-ferrite as a function of Mn content (crosses and open circles, respectively). Values for the spin-wave linewidth (solid circles) are also shown.

The results of the measurements of ΔH_{eff} at both low and high field, outside the field interval for degenerate, low wave number magnons, are shown in Fig. 2 by the crosses and open circles, respectively. It is clear that the high-field ΔH_{eff} decreases rapidly with increasing Mn content, whereas the **low-field effective linewidth is independent of the MN level. The two values are about the same at the highest MN level available, 0.1 Mn at.%/ formula unit.**

These Li-ferrite results are rather revealing. The decrease in the high-field ΔH_{eff} with increasing Mn has been measured before,[8] but was attributed to the decrease in the Fe^{2+} to Fe^{3+} magnetic losses. If this were the case, the low-field ΔH_{eff} would decrease with increasing Mn content as well. However, we see that the low-field losses remain constant. It therefore appears that field-dependent dielectric losses are influencing the measured effective linewidth parameters. **The data in Fig. 2 indicate that the dielectric losses at high field are essentially reduced to zero at 0.1 Mn at.%/formula unit. Figure 2 also shows measured values of the spin-wave linewidth for magnons at approximately** 4.5 GHz (solid points). These linewidths are roughly independent of the Mn level and half the 10 GHz low-field ΔH_{eff} values.

Discussion

Apart from the GGG data of Ref. 7, the idea of microwave dielectric losses in ferrite materials which increase with field is one which has received little attention. The dielectric loss tangent is an important parameter in ferrite device computations. The present results indicate that this parameter can depend on field. These field dependences should prove to be a topic for interesting future work.

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