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Microwave Properties of Fine Grain Polycrystalline Yttrium Iron Garnet

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Parallel pump and subsidiary absorption thresholds at 9.1 GHz and effective linewidth (ΔH_{eff}) at 9.9 GHz have been measured for polycrystalline YIG samples with average grain diameter a_0 from 1 to 30 μ. The spin-wave linewidths extrapolated to zero wavenumber, $\Delta H_{k\to 0}$, vary as a_0^{-1}. The ΔH_k for $a_0=1$ μ shows an inverse k dependence. A simple model in which the spin-wave transit time across individual grains limits ΔH_k explains the a_0^{-1} dependence but not the observed k dependences for ΔH_k. The high-field ΔH_{eff} is 5.5 Oe for $a_0=1$ μ and varies as $a_0^{-1/2}$. These ΔH_{eff} are significantly larger than single-crystal linewidths. Two-magnon interactions cannot contribute to the high-field ΔH_{eff}. A recently proposed magnetostriction mechanism is consistent with the $a_0^{-1/2}$ dependence, but the predicted magnitudes are much smaller than observed.

It is well known that fine graining can improve the high power properties of ferrites,[1] but the physical origin of the effects is not understood. In this study, a unified picture of grain size influences on the spin-wave linewidth and effective linewidth in polycrystalline YIG has been obtained. The data provide several clues to the origin of these properties.

The microwave data were obtained on spherical samples of YIG made by hot pressing conventionally prepared powders. One series was made by hot pressing to a small grain size (average grain diameter $a_0<1$ μ) and then annealing to obtain larger a_0 (HA series). In a second set (HP series), the material was hot pressed directly to the desired grain size. The high-power data were obtained using standard techniques.[2] Effective linewidths were measured as described in Ref. 3, except for refinements to achieve higher sensitivity.[4] The HP series samples generally exhibited smaller spin-wave linewidths (ΔH_k) and smaller ΔH_{eff} than the HA series materials, presumably due to slightly different grain size distributions.

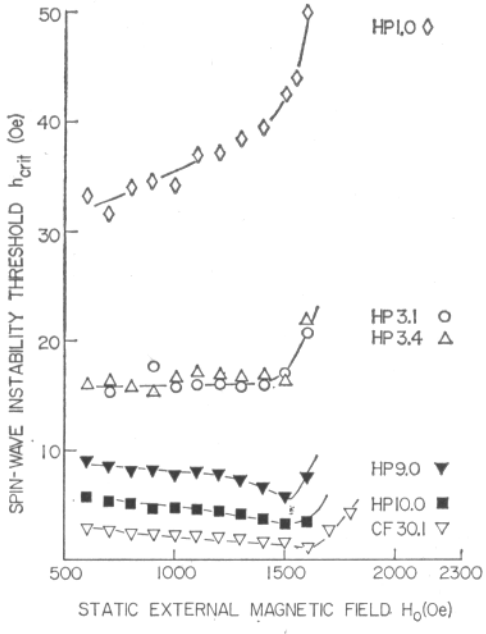

FIG. 1. Spin-wave instability threshold h_{crit} as a function of the static external magnetic field H_0 for parallel pumping at 9.1 GHz.

The parallel-pump threshold h_{crit} is shown as a function of static external field for the HP samples in Fig. 1. The sample with $a_0=30.1$ μ (CF 30.1) was prepared by conventional firing. The h_{crit} for $a_0=1$ μ is over thirty times greater than for the 30-μ grain size. The positive slope for the low-field part of the butterfly curve for $a_0=1$ μ results in an inverse k dependence for ΔH_k. The larger grain samples show the usual weak linear k dependence. The ΔH_k extrapolated to zero wavenumber ($k=0$) exhibit a clear a_0^{-1} dependence, as shown in Fig. 2.

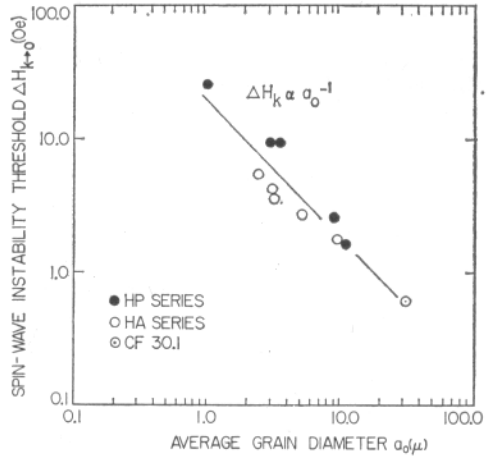

FIG. 2. Parallel pump spin-wave linewidth ΔH_k extrapolated to $k=0$ as a function of the average grain diameter a_0 for data at 9.1 GHz.

This inverse k dependence can be qualitatively explained by a model, recently proposed by Vrehen *et al.*,[5] in which the lifetime of the excited spinwave is limited by the transit time for the mode across individual grains, $\tau_k \approx a_0/|\mathbf{v}_g|$, where $\mathbf{v}_g$ is the spin-wave group velocity. The transit time limited linewidth

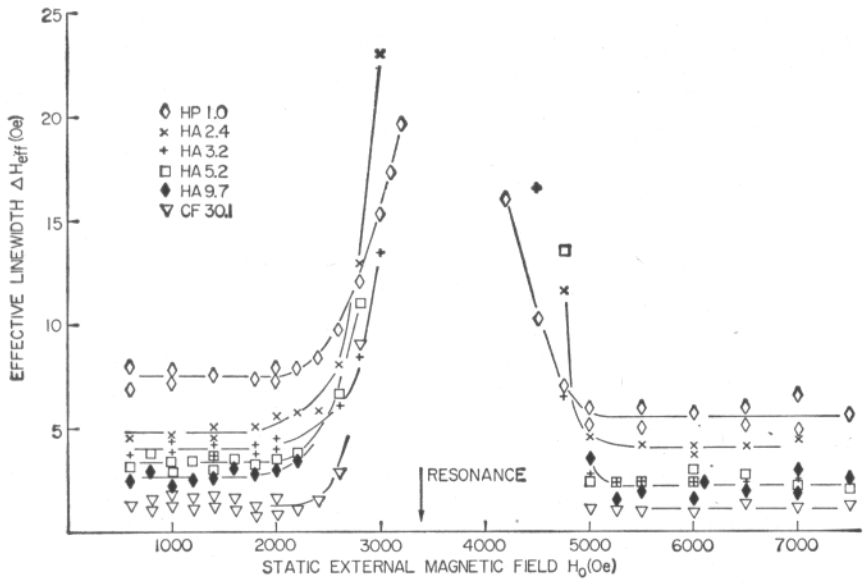

FIG. 3. Effective linewidth ΔH_{eff} as a function of static external magnetic field H_0. The ΔH_{eff} were obtained from susceptibility data at 9.9 GHz.

$\Delta H_k{}^{(t)}$ is given by

$$\Delta H_k{}^{(t)} = 1/\gamma\tau_k = |\mathbf{v}_g|/\gamma a_0, \qquad (1)$$

where γ is the gyromagnetic ratio ($\gamma \approx 1.76\times10^7$ Oe^{-1} sec^{-1}). The a_0^{-1} dependence of $\Delta H_{k\to0}$ indicates that the model is qualitatively correct and that $|\mathbf{v}_g|$ for the lowest threshold mode does not change appreciably with grain size. If Eq. (1) is applied to the data in Fig. 2, $|\mathbf{v}_g|$ is calculated to be on the order of 10^4 cm/sec.

Since $|\mathbf{v}_g| = \nabla_k\omega_k$, where ω_k is the spin-wave frequency, the transit time model can also be used to calculate the k dependence of $\Delta H_k{}^{(t)}$. The analysis results in a linear k dependence for $a_0 > 10\ \mu$ ($k > 10^5$ cm^{-1}) but the slope is somewhat larger than the data indicate. Moreover, the theoretical k dependence for $1\ \mu < a_0 < 3\ \mu$ has a sharp minimum for k in the 1–2×10^5-cm^{-1} range, in complete disagreement with the data. Data which are in better agreement have been obtained on porous YIG,[6] where an independent grain transit time model is somewhat more applicable because of the voids between grains.

The effective linewidth results are summarized in Fig. 3. Essentially, ΔH_{eff} expresses the microwave loss in linewidth units and is useful in the comparison of off-resonance loss data with conventional linewidth results. In the vicinity of resonance (arrow in Fig. 3), ΔH_{eff} is on the order of ΔH (30–100 Oe for most of the samples). Far from resonance, ΔH_{eff} is much smaller and field-independent. The low-field values are slightly larger than the high-field values and the off-resonance ΔH_{eff} varies as $a_0^{-1/2}$.

The large ΔH_{eff} in the vicinity of resonance for polycrystals is due to two-magnon interactions and has been discussed extensively. See, for example, Ref. 3. The high-field ΔH_{eff} is a measure of the microwave losses in the absence of any two-magnon contribution. Even so, the lowest observed ΔH_{eff}, 1 Oe for CF30.1, is still substantially larger than single-crystal linewidths. The small increase in ΔH_{eff} at low field is probably due to two-magnon relaxation related to coupling to degenerate high k modes. The origins of the large off-resonance ΔH_{eff} remain unexplained. The $a_0^{-1/2}$ dependence excludes a transit time explanation. Schlömann has proposed that magnetoelastic scattering may be important.[7] His theory is consistent with the observed $a_0^{-1/2}$ dependence but the calculated values are several orders of magnitude smaller than indicated by the data.

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