Comparison of Effective Linewidth and FMR Linewidth at 10 GHz in Ho Substituted YIG

John R. Truedson, Kevin D. McKinstry, and Carl E. Patton
Department of Physics, Colorado State University, Ft. Collins, Co. 80523, U.S.A.

***Abstract*-The effective linewidth and FMR linewidth techniques were applied at 10 GHz and room temperature to rare earth holmium substituted yttrium iron garnet (HoYIG) spheres. Linewidths were determined for HoYIG spheres with varying amounts of substituted Ho. The FMR linewidth and effective linewidth measured for the HoYIG samples ranged from 4 - 240 Oe. The measured linewidths from the different techniques were compared to determine the sensitivity of the effective linewidth technique to various loss mechanisms over a wide field range. It is found that the linewidths determined from the different techniques track closely. The high field effective linewidth agrees with the measured FMR linewidth for all but the smallest Ho substitution.**

I. Introduction

The standard technique to study microwave losses in ferrites is ferromagnetic resonance (FMR). The analysis of losses by FMR techniques at a given frequency strictly applies only to the positive external static field that satisfies the FMR condition. The "effective" linewidth technique, however, can be used to study intrinsic losses in materials for fields well above the resonance field [1,2]. The high field effective linewidth provides a good measure of these "intrinsic" losses, with minimal influence due to two magnon scattering loss contributions related to sample inhomogeneities, etc. In many cases, these intrinsic losses are much lower than the FMR losses and the high field effective linewidth, ΔH_{eff}, is much smaller than the FMR linewidth, ΔH. This work, however, focuses on rare earth substituted yttrium iron garnet (YIG) for which rapid relaxation losses dominate [3,4]. In this case, the high field effective linewidth and FMR linewidth are expected to be nearly the same. In this study, measurements of both ΔH and ΔH_{eff} at 10 GHz were made on polished spheres of $(Ho_xY_{(1-x)})_3Fe_5O_{12}$ single crystals, with x ranging from 0.0005 to 0.04.

The 10 GHz intrinsic linewidth in highly polished pure single crystal YIG samples is less than 1 Oe. For small amounts of Ho substitution, the linewidth increases in proportion to the amount of substitution. At 10 GHz, the linewidth increases at a constant rate of about 50 Oe per atomic percent Ho substitution (e.g., x=0.01 yields a linewidth of 50 Oe.). The intrinsic linewidth can, therefore, then be increased in a controlled manner by substituting holmium in place of yttrium. This increased linewidth is a result of the increased microwave loss due to strong rare earth holmium coupling with the ferrite lattice [3]. The next section discusses the FMR linewidth technique and linewidth measurements for the HoYIG samples used in this work.

Manuscript received February 17, 1992. This work was supported in part by the United States Office of Naval Research, Contract N00014-90-J-4078.

II. FMR Linewidth Measurements

FMR Linewidths were determined for six highly polished spheres of single crystal $(Ho_xY_{(1-x)})_3Fe_5O_{12}$ with x ranging from 0.0005 to 0.04. FMR linewidths were measured using a modified Varian EPR system with field modulation for spherical HoYIG samples at 10 GHz. The samples were placed one-half wavelength from the end inside a cavity short. The external static field was applied perpendicular to the microwave field. The derivative linewidth was measured for each sample. The conventional half-power FMR linewidth was determined by multiplying the derivative linewidth by $\sqrt{3}$, based on the assumption of a Lorentzian lineshape. Fig. 1 shows a plot of the derivative absorption versus external static field for the HoYIG sample with x = 0.03. The derivative linewidth measured for this sphere was 96.5 ± 0.3 Oe, which gives a half-power FMR linewidth of 167.1 ± 0.5 Oe.

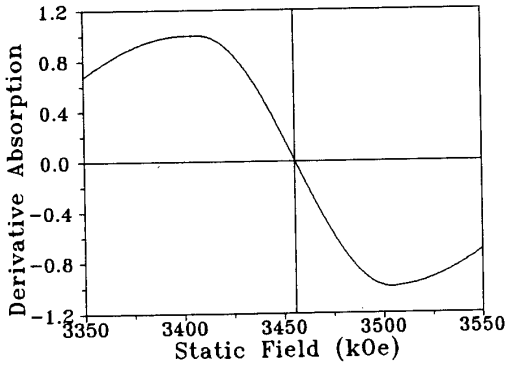

Fig. 1. Plot of derivative absorption vs. external static field for a HoYIG sample of 3.0% Ho at 10 GHz.

0018-9464/92$03.00 © 1992 IEEE

FMR linewidths were determined for the 6 HoYIG samples used in this work. The half-power FMR linewidths ranged from 35 to 240 Oe. Fig. 2 shows the plot of half-power FMR linewidth versus atomic percent Ho subsitution for the 6 samples. The increase, as expected, is linear with a rate of increase of 50 Oe per atomic percent Ho. The straight line extrapolates to 20 Oe at x=0 . This non-zero intercept indicates, as explained in the next section, that other loss mechanisms are responsible for the most of the linewidth in the lowest holmium substituted samples.

III. Effective Linewidth Measurements

The method described in [1,5] was used to determine the high field effective linewidth at 10 GHz for the samples used in this work. The samples were placed in the center of a TE_{011} cylindrical microwave cavity. The external static field H_{ext} was applied perpendicular to the microwave field. Measurements of the cavity frequency ω_{cav} and cavity quality factor Q_{cav} vs. H_{ext} were obtained for the range of 1 - 11 kOe. Effective linewidths were determined for the entire field range except for fields very close to the FMR field. At fields very close to the FMR field, the uniform mode precession in the sample absorbs almost all of the power in the cavity. The measured effective linewidths for the Ho substituted YIG spheres range from 4 to 240 Oe, compared to an intrinsic linewidth for high purity single crystal YIG of less than 1 Oe. These effective linewidths also increase with the amount of Ho in the YIG material [3,4]. As explained above, this increase in linewidth is due mainly to the rapid relaxation process in the Ho substituted YIG. The high field effective linewidths and FMR linewidths for the HoYIG samples are summarized in Table I.

The high field effective linewidths, ΔH_{eff}^{HF}, were compared to the measured half-power FMR linewidths for the HoYIG spheres. Fig. 3 shows the high field effective linewidth vs. FMR linewidth for the 6 Ho substituted YIG spheres summarized in Table I. The figure clearly indicates

Table I
High field effective and FMR linewidths for the Ho substituted YIG samples.

% Ho	ΔH_{FMR}	ΔH_{eff}^{HF}
0.05	20.9 ± 0.3	3 ± 1
0.10	30.2 ± 0.3	37 ± 1
0.40	45.6 ± 0.3	40 ± 2
1.0	55.1 ± 0.4	64 ± 2
3.0	167.1 ± 0.5	168 ± 2
4.0	233.3 ± 0.7	235 ± 2

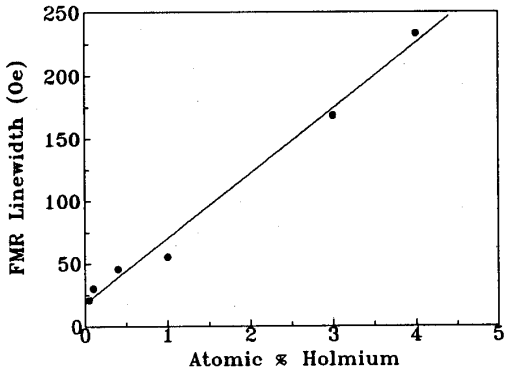

Fig. 2. Plot of FMR linewidth vs. atomic % Ho substitution for the HoYIG samples at 10 GHz.

a linear relation between the high field effective linewidth and the FMR linewidth. The slope of the line in Fig. 3 is 1.02 ± 0.05, which indicates that the high field effective linewidth and half-power FMR linewidth results track closely. The lowest linewidth sample lies somewhat below the line in Fig. 3. Here, ΔH is bigger than the high field ΔH_{eff}^{HF} due to the influence of inhomogeneities on the FMR losses, as discussed below.

The effective linewidths for the field range of 1 - 11 kOe can provide additional information on loss mechanisms near the FMR field. For losses dominated by rapid relaxation processes, the effective linewidth vs. field H is expected to be constant. Data on $\Delta H_{eff}(H)$ vs. H, following [1,2], are shown in Fig. 4 for three samples. For the sample with x = 0.03, the effective linewidth is 170 ± 5 Oe for the entire field range of 1 - 11 kOe. For the sample with x = 0.01, the effective linewidth is around 60 Oe, but increases slightly near the FMR field at 3.5 kOe. The low field effective linewidth is also higher than the high field effective linewidth.

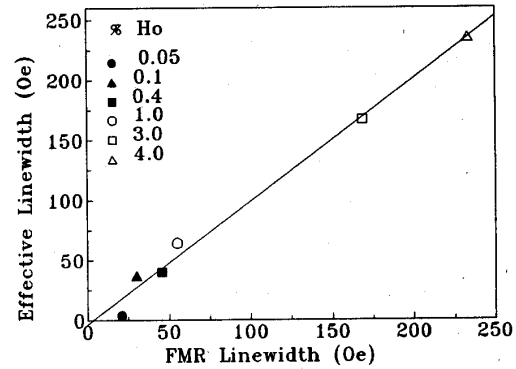

Fig. 3. Plot of high field effective linewidth vs. FMR linewidth for each of the Ho substituted YIG spheres at 10 GHz.

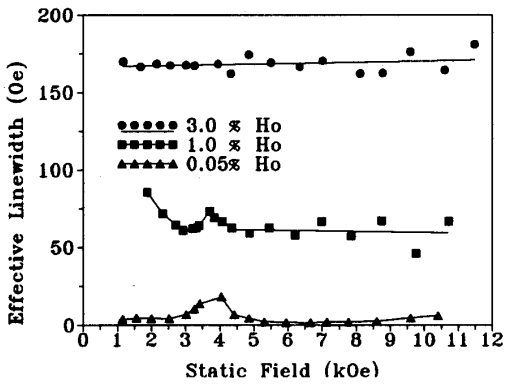

Fig. 4. Plot of effective linewidth vs. static field for HoYIG samples of 3.0% (●), 1.0% (■), and 0.05% (▲) Ho at 10 GHz.

Losses due to inhomogeneities increase the linewidth slightly near the FMR field and below resonance for this sample. The high field effective linewidth for the smallest Ho substitution, x = 0.0005, is 2 - 4 Oe, and increases to 18 - 20 Oe near the resonance field. The higher value for the effective linewidth near the resonance field agrees very well with the FMR measured linewidth of 20.9 Oe. The effective linewidth results for the smallest Ho substituted YIG sphere indicate that the FMR linewidth for this sample is almost completely dominated by two magnon scattering loss.

IV. Summary

The effective linewidth and FMR linewidth techniques were applied to rare earth holmium substituted YIG spheres. The linewidth in the spheres is dominated by a rapid relaxation process that is field independent. The FMR linewidth was compared to the effective linewidth for each of the samples used in this work to determine the reliability of the effective linewidth technique. The effective linewidth tracks closely with the FMR linewidth for the samples. The results indicate that the effective linewidth technique provides accurate linewidth measurements sensitive to loss mechanisms over a range of fields.

Aknowledgments

Dr. J. J. Green, Raytheon Company, Lexington, MA. is acknowledged for providing the holmium substituted YIG samples used in this work. Dr. K. B. Hathaway, United States Office of Naval Research, Washington, D.C. is acknowledged for suggesting this work.

References

[1] C. E. Patton and T. Kohane, "Ultrasensitive technique for microwave susceptibility determination dowm to 10^{-5}," *Rev. Sci. Instr.*, vol. 43, pp. 76-79, 1972.

[2] C. E. Patton, "Effective linewidth due to porosity and anisotropy in polycrystalline yttrium iron garnet and Ca-V-substituted yttrium iron garnet at 10 GHz," *Phys. Rev.*, vol. 179, No. 3, pp. 352-356, 1969.

[3] J. H. Saunders and J . J. Green, "High-power characteristics of low-magnetization garnets," *J. Appl. Phys.*, vol. 32, pp. 161S-165S, 1961.

[4] J. Nicolas, "Microwave Ferrites," in *Ferromagnetic Materials*, vol II, E. P. Wohlfarth, Ed., Amsterdam: North-Holland, 1980, pp. 243-296

[5] J. R. Truedson, K. D. McKinstry, and C. E. Patton, "Effective linewidth due to conductivity losses at 10 - 60 GHz in barium ferrite," *Phys. Rev. B*, in press.