Bull. Mater. Sci., Vol. 2, Number 3, August 1980, pp. 181–186. © Printed in India.

Wave-vector dependence of spin-wave line-width in yttrium iron garnets

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MS received 15 May 1980

Abstract. The wave-vector dependence of the spin-wave line-width in yttrium iron garnets has been studied for samples of grain diameter varying from 1·2 μm to 12 μm. An expression for the spin-wave line-width as a function of wave-vector and grain diameter has been obtained, which agrees satisfactorily with experiment.

Keywords. wave-vector; spin wave; yttrium iron garnets.

1. Introduction

The variation of spin-wave line-width ($\triangle H_k$) and its dependence on the spin-wave vector (k) for different average grain diameter (d) in polycrystalline ferrites and garnets has been discussed by several workers (Vrehen 1966; Patton 1969; Scotter 1972). It is now well established that $\triangle H_{k\to 0}$ varies inversely with grain diameter d for $2 \leqslant d \leqslant 10\,\mu$m, both in dense as well as porous samples (Patton 1970). This has been qualitatively explained by Vrehen *et al* (1969) and Patton (1970) on the transit-time independent grain model. In this a spin-wave gets excited inside a grain, propagates and gets annihilated at the grain boundary in a time interval $\tau = d/v_g$, where v_g is the group velocity of the spin-waves. In this model v_g is assumed to be independent of the grain diameters. τ is experimentally determined from the spin-wave line-width using the relation $\tau = 1/\gamma \triangle H_k$ where γ is the gyromagnetic ratio and is equal to $1{\cdot}76 \times 10^7$ Oe^{-1} sec^{-1}.

The study of the dependence of $\triangle H_k$ on k shows that $\triangle H_k$ varies linearly with k (Patton 1970). The slope of the $\triangle H_k$ vs k straight line is a sensitive function of d. For large grain size the slope is positive and $\triangle H_k$ increases with k. As the grain size decreases the slope also decreases and at a critical grain size (d_0), the slope changes its sign and $\triangle H_k$ decreases with increase in k (Patton 1970). Patton has attempted to explain this result on the basis of the deviation from $\theta_k = \pi/2$ condition for the instability threshold in the parallel pump experiment. Such an approach leads to a minimum in the $\triangle H_k$ vs k curve for small grain diameters which has not been observed for dense samples.

With a view to understand the possible mechanism which may account for the observed d-dependence of the slope we have investigated the k-dependence of $\triangle H_k$ as a function of average grain size in dense polycrystalline garnets.

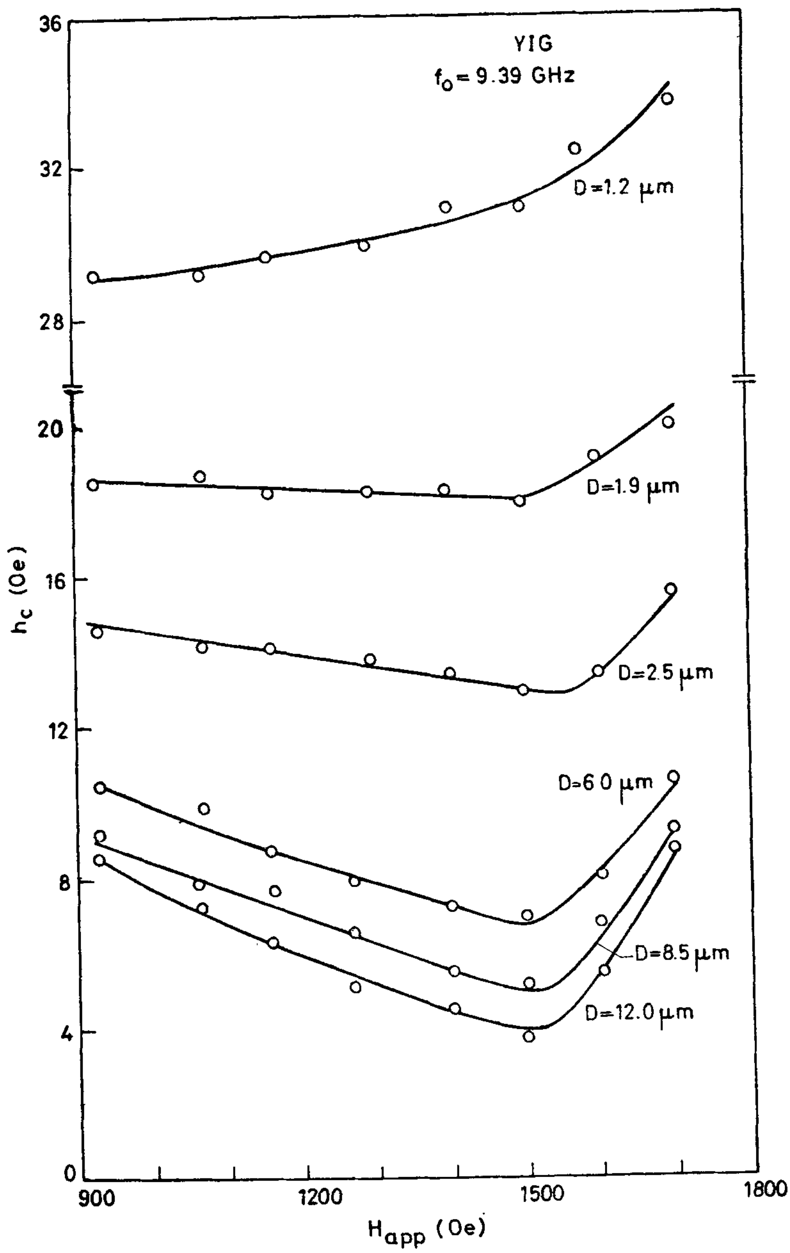

Figure 1. The variation of the critical field h_c as a function of the static applied field H_{app} in YIG at 9·39 GHz. The observations were made in the parallel-pump configuration.

2. Experimental

Polycrystalline yttrium iron garnets (YIG) samples with densities greater than 98·5% of the x-ray density have been prepared using the hot pressing and normal sintering technique. The average grain diameter for these samples ranges from 1·2 μm to 12 μm.

A high power microwave bench giving 60 kW peak power and operating at 9·39 GHz was used to study the parallel pump instability threshold (h_c) in the polycrystalline samples. The samples were mounted in the centre of a TE_{104} cavity.

3. Results

The instability threshold field h_c has been observed as a function of the applied d.c. magnetic field for different grain diameters. The results are given in figure 1.

The spin-wave line-width (ΔH_k) is related to the critical field h_c through the relation

$$h_c = \omega \Delta H_k / \omega_m \sin^2 \theta_k \tag{1}$$

where ω is the operating frequency, $\omega_m = \gamma 4\pi M_s$ and θ_k is the angle between the **k**-vector of the spin-wave and the direction of the applied field. The h_c vs. H_{pp} curve in figure 1 gives the value of ΔH_k in (1) for $\theta_k = \pi/2$ up to $h_{c\,\min}$.

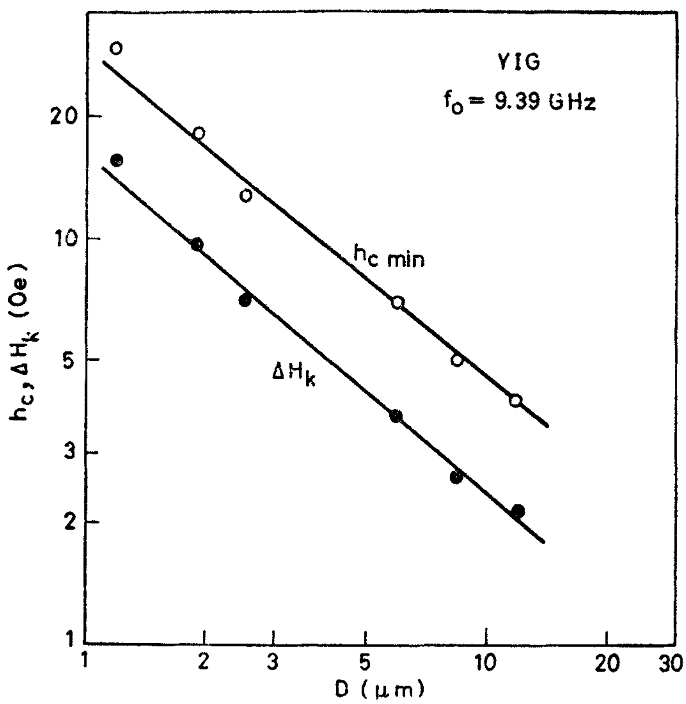

Figure 2. The dependence of the $h_{c\,\min}$ and ΔH_k on grain diameter in YIG at 9·39 GHz. The minimum in the critical field occurs for $\theta_k = \pi/2$ magnons. ΔH_k has been obtained from $h_{c\,\min}$ using equation (1) of the text.

A log-log plot of $h_{c\,min}$ and $\triangle H_k$ as a function of grain diameter is given in figure 2. The k-dependence of $\triangle H_k$ is given in figure 3. In figure 4 is plotted the observed variation of $\triangle H_{k\to 0}$ with d^{-1}.

4. Discussion

According to the transit time model

$$\triangle H_k = 1/\gamma\tau = v_g/\gamma d. \qquad (2)$$

For the parallel pump experiment, $v_g = 2\gamma Dk$, where D is the exchange stiffness constant. Hence, $\triangle H_k = 2Dk/d$. The group velocity in fine grain materials for $k \to 0$ would tend to a constant value which may be given by $2\gamma Dk_0$. This

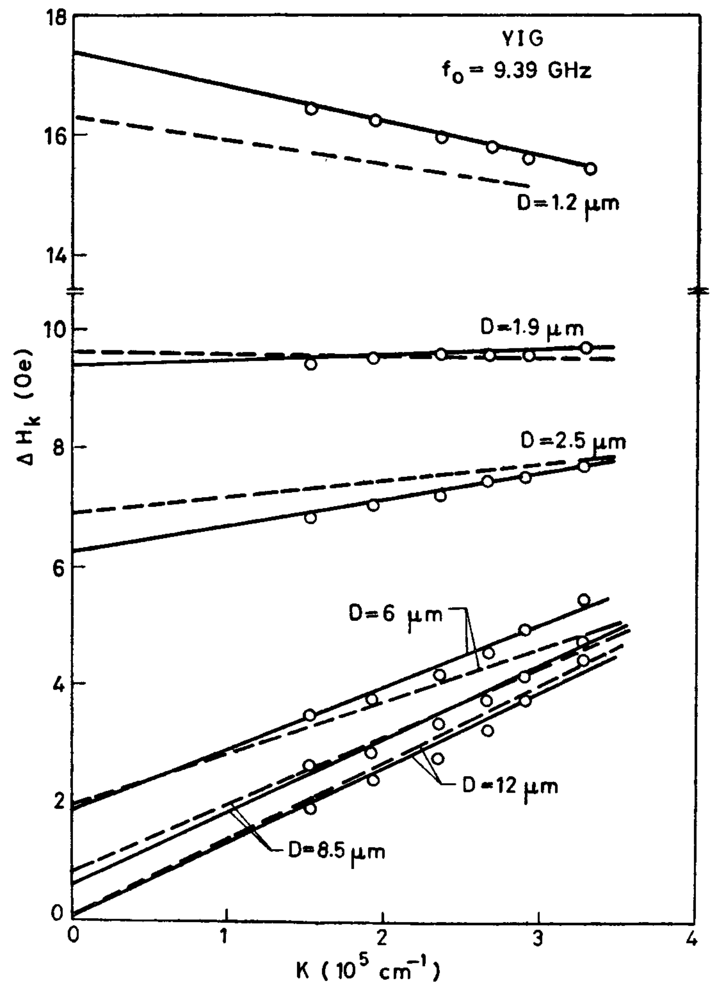

Figure 3. The dependence of $\triangle H_k$ on the wave vector k for different values of the grain diameter for YIG. The solid line and the points show the experimental data. The dashed line is the theoretical curve obtained from equation (4) of the text with $D = 5 \times 10^{-9}$ Oe-cm^2, $K_0 = 2{\cdot}16 \times 10^5$ cm^{-1} and $C_0 = -1{\cdot}7$ Oe,

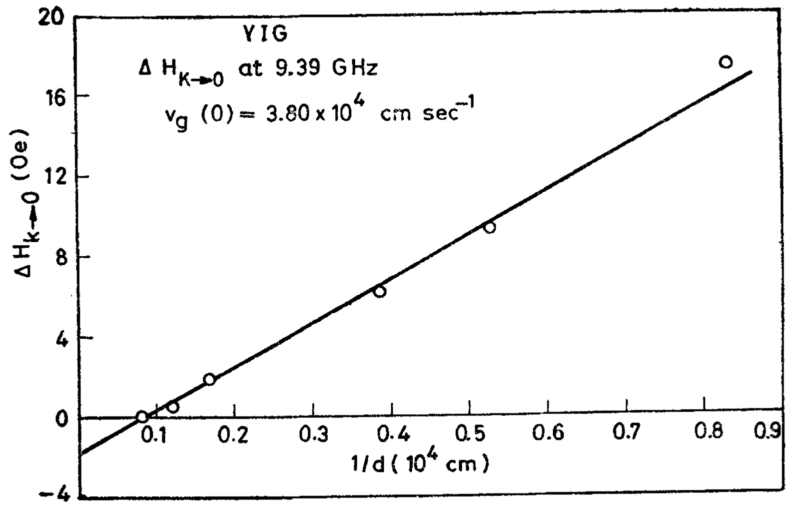

Figure 4. The dependence of the spin-wave line-width for $k \to 0$, $\triangle H_{k\to 0}$ on d^{-1} where d is the grain diameter for YIG.

follows as in the limit $k \to 0$ the spin wave mode goes over to the magnetostatic mode. Hence we may take.

$$\triangle H_{k\to 0} = 2Dk_0/d + C_0 \tag{3}$$

where C_0 is a constant independent of d.

For finite k, the experimental observation can be fitted to the following equation,

$$\triangle H_k = \frac{2Dk_0}{d}\left[1 + \xi(d)\frac{k}{k_0}\right] + C_0, \tag{4}$$

where

$$\xi(d) = \frac{d - d_0}{d + d_0} \; \frac{d}{3d_0}. \tag{5}$$

Here d_0 is a characteristic grain diameter for which the spin-wave line-width becomes independent of k.

Using equation (2) and taking the observed variation of $\triangle H_{k\to 0}$ with d^{-1} given in figure 4, we obtain

$$k_0 = 2{\cdot}16 \times 10^5 \, cm^{-1}, \tag{6}$$

and $$C_0 = -\, 1{\cdot}7 \, Oe. \tag{7}$$

Here D has been taken as 5×10^{-9} Oe– cm^2, the value appropriate for YIG.

Using the value of k_0 and C_0 given in (6) and (7), we have plotted theoretical curves based on (4) in figure 3 and shown them by dashed lines. The agreement with experiment is satisfactory.

5. Conclusion

The wave-vector dependence of the spin-wave line-width in YIG has been studied as a function of grain diameter. It has been possible to obtain an expression for the spin-wave line-width which is dependent on the grain diameter and the wave-vector, and which is in satisfactory agreement with experiment.

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