IV-2 DEPENDENCE OF PEAK POWER THRESHOLD UPON $\frac{\omega_M}{\omega}$

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Recently it has been reported[1] that a significant increase in peak power performance could be achieved in latching type ferrite phase shifters through the use of materials of low ω_M/ω, $\omega_M = \gamma 4\pi M_s$. Because of the obvious importance of such a possibility, we decided to examine the dependence of peak power threshold upon ω_M/ω.

The theoretical work of Suhl[2] and Schlömann[3] has shown that for a saturated material the critical rf field is given by

$$h_{crit} = C\Delta H_k / \left(\frac{\omega_M}{\omega}\right),$$

where ΔH_k is a spin wave linewidth which is proportional to the spin wave relaxation rate. The factor C is a function of the dc biasing field, $4\pi M_s$, and also depends upon whether the rf field and $4\pi M_s$ are perpendicular ($\perp$pumping) or parallel ($\parallel$pumping). For each type of pumping, C is the order of unity.

In a latching phase shifter the ferrite is at remanence which is a partially magnetized state. For a partially magnetized material, the local effective internal field depends upon dc and rf demagnetization due to the local domain configuration. Hence each point within the material can be thought of as having a threshold characteristic of a saturated material with a biasing field equal to the local effective internal field will be such that the wave number k of the excited spin wave is increased. Taft[1] et al found that the threshold field increases much more rapidly than $(\omega_M/\omega)^{-1}$ and attribute this to an abrupt increase in ΔH_k as increasing k causes the spin wave frequency $\omega_k = \omega/2$ to move through the top of the long wavelength portion of the spin wave manifold.

Because ΔH_k is very sensitive to the microstructure of a poly-crystalline material and because we wished to study the dependence of ΔH_k only upon k and ω_M/ω, we selected two compositions and chose to vary ω on each. YIG ($4\pi M_s$ = 1740 gauss) was measured at 5.53, 9.21, and 16.8 Gc, and Trans Tech G-610 (an aluminum substituted YIG, $4\pi M_s$ = 675 gauss) was measured at 2.98, 5.53, and 9.21 Gc. The same spherical sample of each composition was placed in a linearly polarized rf field in a resonant cavity for each frequency. Parallel and perpendicular pump measurements were made at room temperature as a function of dc magnetic field.

The type of result obtained is illustrated in Fig. 1. The theoretical curves, which come from Suhl[2] for perpendicular pumping and Schlomann[3] for parallel pumping, have been fitted to the experimental curves at the point of lowest threshold and assume that ΔH_k is independent of dc field. The fact that the experimental curves lie above the theoretical curves is due to a dependence of ΔH_k upon k. At dc fields below $4\pi M_s/3$, a sphere is partially magnetized. Because the coercive force of YIG and G-610 is less than 1 oe, $4\pi M_s \cong 3H_{dc}$ for $H_{dc} < 4\pi M_s/3$. Since the remanent magnetization is $4\pi M_r \cong \frac{2}{3} 4\pi M_s$ for these materials, the thresholds for the remanent state occur at $H_{dc} = \frac{2}{3}\frac{4\pi M_s}{3}$, as indicated in Fig. 1. At remanence the parallel pump threshold is considerably lower than for perpendicular pumping. At $H_{dc} = 0$, the material is completly demagnetized and the two thresholds have coalesced.

From the theories of Suhl[2] and Schlömann[3], the dependence of ΔH_k upon H_{dc} can be translated to a dependence of ΔH_k upon k as shown in Fig. 2. Work by Kasuya and LeCrew[4] on single crystal YIG showed that

$$\Delta H_k = A + Bk.$$

Although our data do not fit this relationship as well as does the single crystal data, we have analyzed our data with best fit straight lines in Fig. 2, and the results are summarized in the following tables.

YIG $4\pi M_s = 1750$ gauss		Perpendicular Pump $k_{top} = 2.53 \times 10^5 cm^{-1}$			Parallel Pump $k_{top} = 0$		
f (Gc)	$\frac{\omega_M}{\omega}$	k_{max} ($10^5 cm^{-1}$)	A (oe)	B (10^{-5}oe.cm)	k_{max} ($10^5 cm^{-1}$)	A (oe)	B (10^{-5}oe.cm)
5.53	.890	3.54	1.48	.18	2.42	1.92	.18
9.21	.535	4.93	1.73	.16	4.21	1.60	.25
16.8	.295	6.85	2.84	.28	6.40	1.73	.35

G-610 $4\pi M_s = 675$ gauss		Perpendicular Pump $k_{top} = 1.47 \times 10^5 cm^{-1}$			Parallel Pump $k_{top} = 0$		
f (Gc)	$\frac{\omega_M}{\omega}$	k_{max} ($10^5 cm^{-1}$)	A (oe)	B (10^{-5}oe.cm)	k_{max} ($10^5 cm^{-1}$)	A (oe)	B (10^{-5}oe.cm)
2.98	.611	3.12	1.63	.03	2.68	1.42	.25
5.53	.329	4.36	1.87	.15	4.05	1.64	.29
9.21	.198	5.85	2.14	.34	5.61	1.88	.33

k_{top} = wavenumber at which ω_k of excited spin wave is equal to frequnecy of top of long wave length portion of spin wave manifold.

The remanent state thresholds are given in Figs. 3 and 4. Theoretical curves, which have been normalized to the threshold measured at the highest frequency for each composition and which are proportional to $(\omega_M/\omega)^{-1}$ and $(\omega_M/\omega)^{-2}$ respectively, are included for both the perpendicular and parallel pumping. The experimental threshold would be proportional to $(\omega_M/\omega)^{-1}$ if ΔH_k were independent of ω_M/ω. Since A, B, and k (remanence) appear to be weak functions of ω_M/ω, ΔH_k (remanence) does not vary as strongly as $(\omega_M/\omega)^{-1}$. Consequently the experimental thresholds fall between the $(\omega_M/\omega)^{-1}$ and $(\omega_M/\omega)^{-2}$ curves.

Conclusions

From our results we wish to emphasize the following conclusions:

1. ΔH_k increases steadily with increasing k and can be approximated by the equation $\Delta H_k = A + Bk$. There is no abrupt increase of ΔH_k as the frequency of the excited spin wave passes above the top of the long wavelength portion of the spin wave manifold.

2. The parallel pump threshold is lower than the perpendicular pump threshold. Parallel pumping may well be the cause of the nonlinear loss observed in remanent devices since most such devices have portions of the ferrite with the rf fields and dc magnetization parallel.

3. The threshold of the remanent state is proportional to $(\omega_M/\omega)^{-n}$ where $1 \leq n \leq 2$. Although a reduction in ω_M/ω does improve peak power performance, it does mean a longer, heavier, costlier device and a large volume of material to contribute to insertion loss. The value then in reducing ω_M/ω will depend upon the trade-off between these advantages and disadvantages.

1. D.R. Taft, J.L. Allen, and G.P. Rodrique, NEREM Record 1966, Vol. 8, pp. 98-99.
2. H. Suhl, J. Phys. Chem. Solids 1, 209 (1957).
3. E. Schlomann, J.J. Green, and U. Milano, J. Appl. Phys. Supp. 31, 3865 (1960).
4. T. Kasuya and R.C. LeCraw, Phys. Rev. Letters 6, 233 (1961).

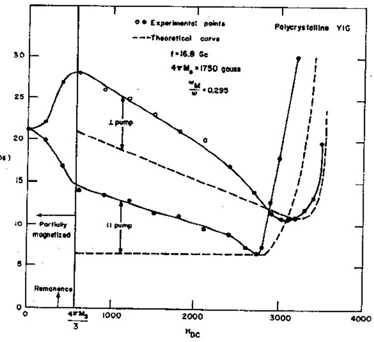

FIG. 1 - Critical RF Field for YIG at 16.9 Gc

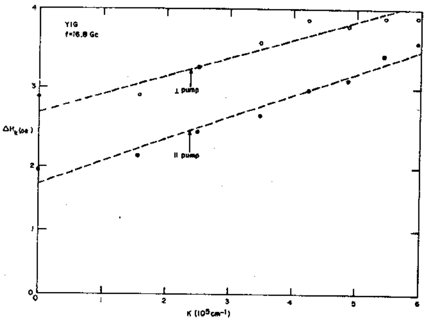

FIG. 2 - Dependence of ΔH_k Upon Wave Number

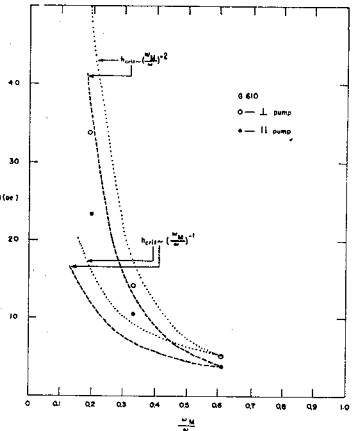

FIG. 3 - Remanent Threshold of YIG

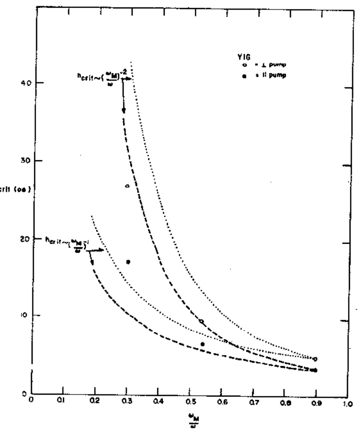

FIG. 4 - Remanent Threshold of G-610