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Parallel-Pumped Instabilities in Magnetic Metal Films*

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Parallel-pumped instability (PPI) susceptibility measurements on several Permalloy magnetic metal films demonstrate a variety of microwave power and dc field-dependent effects. In the low-field spin-wave range, thick films may show either of two distinct kinds of behavior, or a combination of both. A qualitative explanation of these behaviors based on varying drive-field coupling to two different sets of modes with wave vectors perpendicular or parallel to the film plane and similar thresholds is suggested. Very thin films have a different characteristic behavior due to severe mode distortion caused by sample shape demagnetization. Lack of correlation between spin-wave relaxation rates and resonance linewidths suggests that inhomogeneous broadening is an important linewidth mechanism.

I. INTRODUCTION

STUDY of the parallel-pumped instability (PPI) of spin waves at microwave frequencies has yielded remarkably detailed information about the fundamental relaxation processes in ferrimagnetic insulators. Though of considerable potential interest, the application of this technique to ferromagnetic metals is difficult experimentally. The chief difficulties are the enormous skin-depth reduction of useful sample volume and the need for magnetrons with their attendant frequency and amplitude noise.

We have made what we believe to be the first useful observations of parallel pumping signals in ferromagnetic metals. These room-temperature observations were made on vacuum-deposited magnetic metal films[1] at 16.7 Gc/sec with pulse powers from 100 to 5000 W. The dc bias field was in the film plane. To obtain observable signal-to-noise ratios the power incident on the cavity was modulated by a high-power-switched circulator. The field dependence of the PPI susceptibility was detected in a gated balanced receiver and displayed on an X–Y recorder.

II. DESCRIPTION OF DATA

The three figures show PPI susceptibility versus H_{dc} for several power levels below and above threshold. H_c marks where the top of the $k=0$ bulk manifold is at half the drive frequency. Figure 1 shows the marked structure observed for some 83:17 Permalloy films. The peaks seem to depend on some kind of resonance of the spin modes with the sample thickness which is crudely related to spin-wave resonance.[2]

Figure 2 shows, for 75:25 Permalloy, another kind of typical behavior. Some important features here are

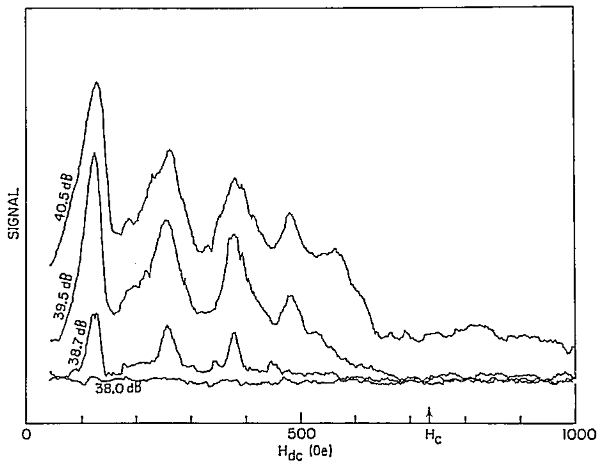

FIG. 1. Parallel-pumping susceptibility above threshold vs H_{dc}. 83:17 Permalloy film 700X-2B-1, 4900 Å. 38 dB=45 Oe. rf field.

the single peak above threshold power and slightly below H_c, the absence of thickness resonance structure, and the increasing susceptibility at constant power for fields below H_c. An intermediate case was observed for 79:21 where both behaviors are superimposed.

Figure 3 represents the general behavior observed

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[1] We are greatly indebted to D. O. Smith and the MIT Lincoln Laboratory Computer Components group for their cooperation in supplying these and many other samples.

[2] M. H. Seavey and P. E. Tannenwald, Phys. Rev. Letters 1, 168 (1958).

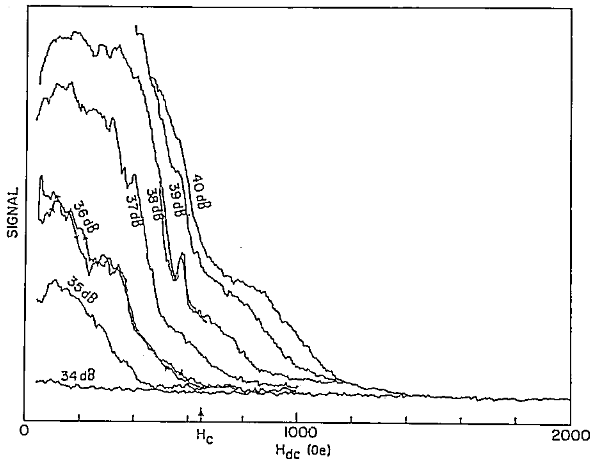

FIG. 2. Parallel-pumping susceptibility above threshold vs H_{dc}. 75:25 Permalloy film 856X-3A-1, 13 385 Å. 34 dB=32 Oe. rf field.

in all very thin (400–100 Å) films. The very large susceptibility observed just above H_c and the rapid threshold increase for slightly larger fields is due to the drastic changes in the mode configurations and mode spectrum arising from thin sample demagnetizing effects.[3]

III. SUMMARY REMARKS

It is difficult from these preliminary results to draw detailed conclusions on relaxation processes in films.

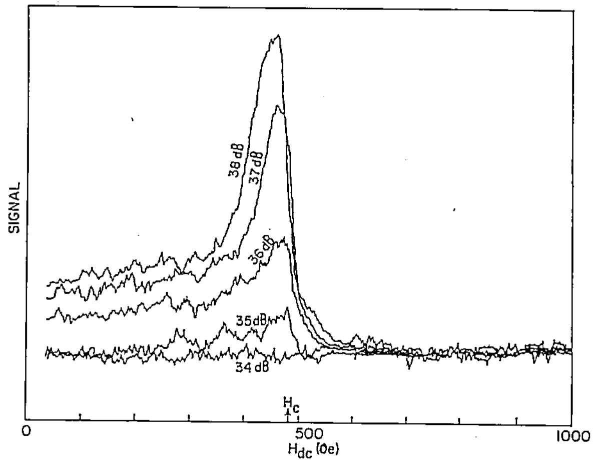

FIG. 3. Parallel-pumping susceptibility above threshold vs H_{dc}. Cobalt film 855X-1B-1, 240 Å. 34 dB=32 Oe. rf field.

[3] J. B. Comly, T. Penney, and R. V. Jones, J. Appl. Phys. 34, 1145 (1963).

The PPI threshold of a pair of spin modes is the product of their relaxation rates and coupling to the longitudinal rf field. In thin films, sample-shape demagnetization forces and exchange forces are of comparable importance, leading to complicated coupling factors at all PPI field values. An example may be the steep rise in susceptibility (fall in threshold power) observed below H_c in Fig. 2 which could be interpreted as an increased coupling due to decreased sample demagnetization forces on in-plane spin waves of decreasing wavelength.

TABLE I. Parallel-pumping data summary for Permalloy films. ΔH_k^{min}=minimum spin-wave linewidth, ΔH_r=resonance linewidth parameter.

Alloy	Thickness (Å)	h_c^{min} (Oe)	ΔH_k^{min} (Oe)	ΔH_r (Oe)
83:17	9610	51	91	424
83:17	4900	48	86	229
83:17	3300	45	81	190
83:17	1700	45	81	126
83:17	~100	45	81	...
79:21	9290	36	69	361
79:21	1140	34	65	105
79:21	405	30	57	80
75:25	13 385	32	66	123
75:25	3105	38	78	206
75:25	435	27	56	82

In thick films it appears that two sets of modes may be competing closely for the lowest threshold, one set with k across the film as indicated by peaks in the threshold and susceptibility, the other with k in the plane and perpendicular to H_{dc} as indicated by a sharp drop in threshold as k increases above the reciprocal sample thickness. If this interpretation based on coupling changes is correct, there seems to be little k dependence of the spin-wave relaxation rates.

Generally speaking, the spin-wave relaxation rates calculated on a simple bulk model are rather similar for all films (56 to 91 Oe) and show little correlation with resonance linewidths (80 to 424 Oe). This lack of correlation is reasonable if the linewidths are mainly due to inhomogeneous broadening (i.e., two-magnon processes).[4] A summary of threshold and linewidth data is presented in Table I.

[4] C. W. Haas, and H. B. Callen in *Magnetism*, edited by G. T. Rado and H. Suhl (Academic Press Inc., New York, 1963), Vol. 1, p. 506.