A wave-vector selective light scattering magnon spectrometer

W. D. Wilber, W. Wettling,[a] P. Kabos,[b] C. E. Patton, and W. Jantz[a]
Department of Physics, Colorado State University, Fort Collins, Colorado 80523

A new type of magnon spectrometer has been developed, based on inelastic light scattering from magnetic excitations. This spectrometer enables one to study magnetic excitations of a specific frequency and wave vector as a function of static field, microwave power, temperature, or any other external experimental parameter. The sample is excited by an applied microwave field and simultaneously probed by laser light. The inelastically scattered light corresponding to a particular magnon wave vector **k** is selected and its intensity at a specific frequency ω_k is recorded. The intensity of this light is a direct measure of the strength of that particular magnetic excitation at **k** and ω_k. Spectra taken in this way present a direct and localized measurement of specific, selectable magnons, in contrast with standard microwave measurements which give only a measure of the total response of all excited modes over the entire sample.

PACS numbers: 07.55. + x, 78.35. + c, 75.30.Ds

INTRODUCTION

With recent developments in high contrast Fabry–Perot interferometry[1] the observation of Brillouin light scattering from magnetic excitations in ferro- and ferrimagnets has been made possible. Much of the work in this area, as reviewed by Borovik–Romanov and Kreines,[2] has been concerned with thermally excited spinwaves. However, the new information which may be obtained from light scattering has created a renewed interest in pumped magnons. Experiments in both the perpendicular and parallel pump configuration have been done on yttrium iron garnet (YIG),[3,4] $CoCO_3$,[5] and K_2CuF_4.[6] In the conventional microwave experiment one measures the reflected power from a cavity as a function of applied static field. The onset of absorption and the excitation of magnons is observed as a change in the reflected power. With Brillouin light scattering, it is possible to detect magnons of specific wave-vector k and frequency ω_k. One can therefore study the characteristics of the pumped magnons directly. The purpose of this paper is to describe a light scattering magnon spectrometer which is both wavevector and frequency selective. This spectrometer can be used to observe specific magnetic excitations as a function of applied static field or any other experimental parameter which may be controlled externally. As an example of spectrometer operation, some parallel pumping results for a YIG thin film are presented.

DESCRIPTION

The general principle of this spectrometer is to use the intensity of the light scattered by a specific magnetic excitation as a measure of its relative strength. This intensity is recorded as a function of some experimental parameter while the material is excited by a microwave field. The unique aspect of this spectrometer lies in the use of a tandem multipassed Fabry–Perot interferometer[1] as a selective detector for light scattering events corresponding to the magnon frequency of interest. This optical system together with the necessary microwave elements are shown schematically in Fig. 1 and described in detail below.

The light scattering part of this spectrometer begins with a single mode laser, in this particular case an argon-ion laser. The incident light is linearly polarized and focussed onto the sample in the microwave cavity. The incident light path indicated by the broken line corresponds to the initial backscattering configuration used to correctly position the sample with respect to the collecting lens. The incident light path indicated by the solid line corresponds to the configuration used in forward scattering to examine small wave-vector excitations. The scattered light is collimated by the collecting lens and passed through a polarization analyzer. A diaphragm placed after the polarizer enables one to selectively examine particular magnon wave vectors by using appropriately placed apertures in the diaphragm as described in Ref. 4. With the physical constraints imposed on the scattering geometry by the cavity, the maximum observable magnon wave vector is about 5×10^4 cm^{-1}.

The microwave power to excite the sample is provided by the system shown in the upper right portion of Fig. 1. A 200-mW frequency stabilized X-band Klystron is currently used to produce a maximum microwave field amplitude of 0.89 Oe at the sample, located at the center of a high Q TE_{102} cavity ($Q\sim3000$) operated at 9.38 GHz. The particular arrangement shown in Fig. 1 is for parallel pumping. A static field applied normal to the page would correspond to the

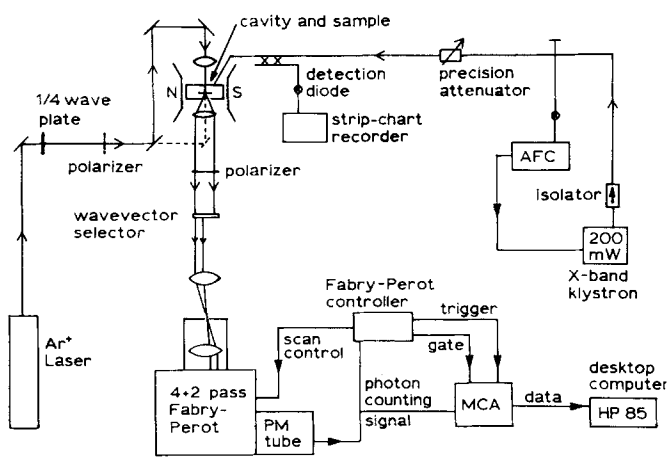

FIG. 1. Block diagram of magnon spectrometer consisting of the microwave source and Fabry–Perot interferometer system.

[a] Permanent address: IAF der FhG, Freiburg D-7800, West Germany.
[b] Visiting Associate Professor from the Slovak Technical University, Bratislava, CSSR.

 0021-8979/84/062533-03$02.40 © 1984 American Institute of Physics

Downloaded 09 May 2003 to 129.82.31.230. Redistribution subject to AIP license or copyright, see http://ojps.aip.org/japo/japcr.jsp

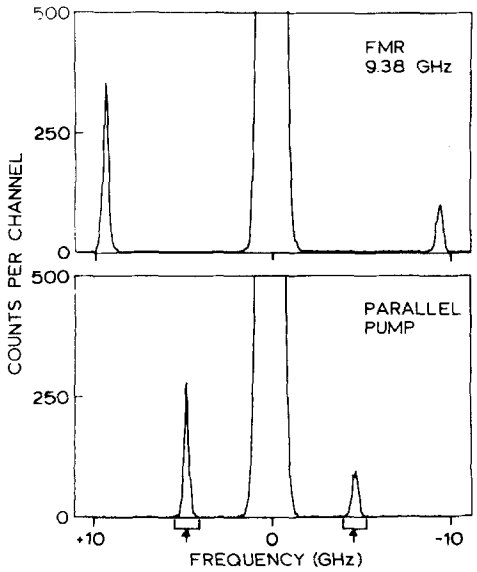

FIG. 2. Spectra of pumped magnons. Top: Spectra for ferromagnetic resonance. Bottom: Spectra for parallel pumped instabilities at one-half the pump frequency.

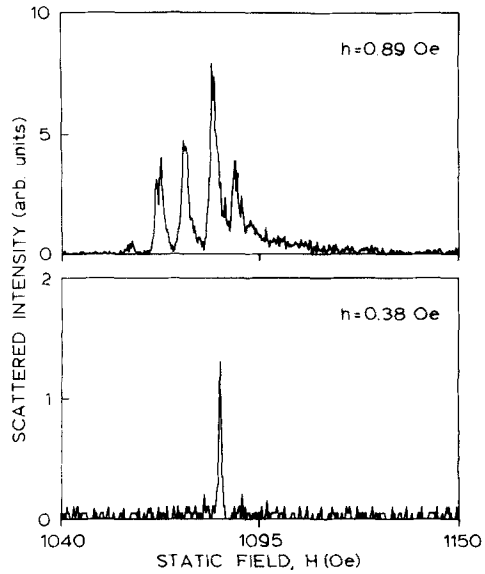

FIG. 4. Intensity of light scattered from parametrically excited spin waves, with $k = 1.7\times10^4$ cm^{-1} and $\theta_k \approx 90°$, as a function of applied field. The sample is a 4.15-μ YIG film and the microwave power is (bottom) less than 0.1 dB above threshold and (top) 7.5 dB above threshold.

usual case of perpendicular pumping and ferromagnetic resonance. The directional coupler and strip-chart recorder enable one to simultaneously measure light scattering signals and microwave absorption.

The conventional mode of operation for a Fabry–Perot is to repeatedly scan the interferometer in frequency (either by translating one mirror or by changing the intracavity pressure) and collect the transmitted light intensity using a multichannel analyzer (MCA) which is synchronously scanned. Then from the MCA contents one can measure the frequency and intensity of the scattered light. Figure 2 shows spectra for (a) ferromagnetic resonance and (b) parallel pumped instabilities taken in this conventional mode.

One key feature of the present spectrometer involves the following modification to the above scheme: The interferometer is scanned as usual using a piezoelectric drive and a sawtooth voltage as shown in Fig. 3(a). The resulting intensity versus time is as in Fig. 3(b). A gate signal from the Fabry–Perot control unit[9] is set to occur during that part of the interferometer scan which covers the frequency region of interest. For the parallel pump spectra of Fig. 3, for example, the frequency of interest is 4.69 GHz and the Stokes and/or anti-Stokes pumped magnon signals (the square bracketed frequency intervals) may be selected. The timing of this gate signal is shown in Fig. 3(c) for the case where the anti-Stokes line is being examined. The gate signal is then applied to the MCA so that scattering events are counted and accumulated only over the frequency range of interest. The gated transmission intensity is shown in Fig. 3(d). The MCA is then advanced slowly in time (typically 1 sec/channel over 1024 channels), as indicated in Fig. 3(e), while the interferometer is scanned several times during the dwell time interval for a particular MCA channel. In this way the signal intensity at the chosen frequency is accumulated in one second intervals and displayed as a function of time. This allows that particular frequency signal to be monitored as a function of static field, temperature, microwave power or any experimental parameter which can be slowly varied.

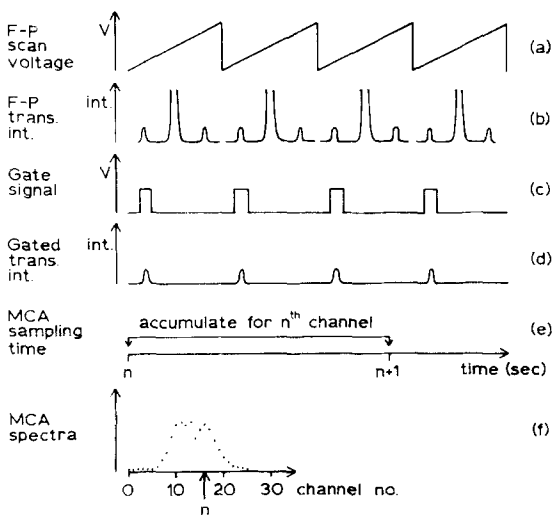

FIG. 3. Relative timing of the (a) scanning voltage, (b) conventional spectra, (c) gating signal, (d) gated transmission, and (e) MCA sampling time along with (f) a typical MCA spectra.

APPLICATIONS

To demonstrate the use of the spectrometer described above we present some data for parallel pumped YIG. The sample was a 4.15 μ (111) YIG film on a gadolinium galium garnet substrate. Figure 4 shows the scattered light intensity from parallel pumped spin waves as a function of applied static field H for two microwave field values. Both spectra are for $k = 1.7\times10^4$ cm^{-1} and $\theta_k = 90°$ spin waves where θ_k is the angle between the static field and the direction of spin wave propagation. One can clearly see the static field range for this particular magnetic excitation. The spectra also shows a rich structure possibly due to discrete magnon resonances.[10] Data taken in this manner are analogous to microwave absorption measurements except that one is able

Downloaded 09 May 2003 to 129.82.31.230. Redistribution subject to AIP license or copyright, see http://ojps.aip.org/japo/japcr.jsp

to selectively examine the excitation spectra of specific magnons generated locally in the sample. Additional data and a more elaborate analysis of these particular parallel pumping data will be presented elsewhere.[4]

ACKNOWLEDGMENTS

We wish to thank Dr. J. D. Adam, Westinghouse Research and Development Center, Pittsburgh, for providing the YIG thin films used in our experiment. This work was supported by the National Science Foundation and Army Research Office under grant no. DMR-801-3727.

[1]J. R. Sandercock, Top. Appl. Phys. **51**, 173 (1982).
[2]A. S. Borovik-Romanov and N. M. Kreines, Phys. Rep. **81**, 351 (1982).
[3]V. N. Venitskii, V. V. Eremenko, and E. V. Matyushkin, Sov. Phys. JETP **50**, 934 (1979).
[4]W. Wettling, W. D. Wilber, P. Kabos, and C. E. Patton (these Proceedings).
[5]V. G. Jotikov and N. M. Kreines, J. Magn. Magn. Mater. **15–18**, 809 (1980).
[6]A. S. Borovik-Romanov, N. M. Kreines, R. Laiho, T. Levala, and V. G. Zhotikov, J. Phys. C **13**, 879 (1980).
[7]Y. H. Liu and C. E. Patton, J. Appl. Phys. **53**, 5116 (1982).
[8]C. E. Patton, Phys. Status Solidi B **92**, 211 (1979); **93**, 63 (1979).
[9]J. Sandercock, J. Phys. E **9**, 566 (1976).
[10]W. Jantz, J. Schneider, and B. Andlauer, Solid State Commun. **10**, 937 (1972).

Downloaded 09 May 2003 to 129.82.31.230. Redistribution subject to AIP license or copyright, see http://ojps.aip.org/japo/japcr.jsp