BRILLOUIN LIGHT SCATTERING ON COBALT-CHROMIUM FILMS

G. Srinivasan and C. E. Patton

ABSTRACT

Brillouin light scattering has been used to observe high frequency thermal magnetic excitations in ion-beam sputtered Co-Cr thin films. The measurements were performed on 82 at. % Co samples, 100 Å, 350 Å and 750 Å in thickness, sputtered on single crystal Si substrates. The Brillouin scattering signals from these Co-Cr films were quite strong. All spectra show scattering due to surface magnons propagating in the film plane. Scattering due to bulk spin waves was found for the two thicker films. From the measured magnon dispersion for the surface mode, Damon-Eshbach theory was used to calculate the magnetization, the perpendicular anisotropy field and the gyromagnetic ratio for the films. The spin wave stiffness parameter was determined from the bulk magnon dispersion. These magnetic parameters are in reasonable agreement with results from ferromagnetic resonance.

INTRODUCTION

Brillouin light scattering is a powerful technique for the characterization of magnetic materials.[1,2] In this technique, the interaction between the incident laser light and magnetic excitations in the material results in scattered light which is frequency-shifted. A Fabry-Perot interferometer is used for the frequency analysis of the scattered light and the Brillouin spectrum, thus obtained, reveals magnon peaks at frequencies corresponding to magnetic excitations in the material. Data on the variation of magnon frequencies with externally controlled parameters, such as the applied static magnetic field and the magnon wave number, can be used to determine magnetic parameters, such as magnetization, anisotropy, g-factor, and exchange stiffness. The purpose of this paper is to report Brillouin light scattering (BLS) measurements of thermal surface and bulk magnons in ion-beam sputtered Co-Cr films. Measurements have been made on 82 at. % Co samples sputtered on (100) Si substrates, 100 Å, 350 Å and 750 Å in thickness.

EXPERIMENT

The Co-Cr films were prepared by ion-beam sputtering using a Kaufman-type ion source.[3] The 12.5 cm diameter Co-Cr target was placed 10 cm away from a rotating silicon substrate. The target was bombarded by a beam of neutralized argon ions, 1.1 keV in energy and 1 mA/cm^2 in current density. The background pressure during deposition was 6×10^{-5} Torr. The deposition rate was 50 Å/minute.

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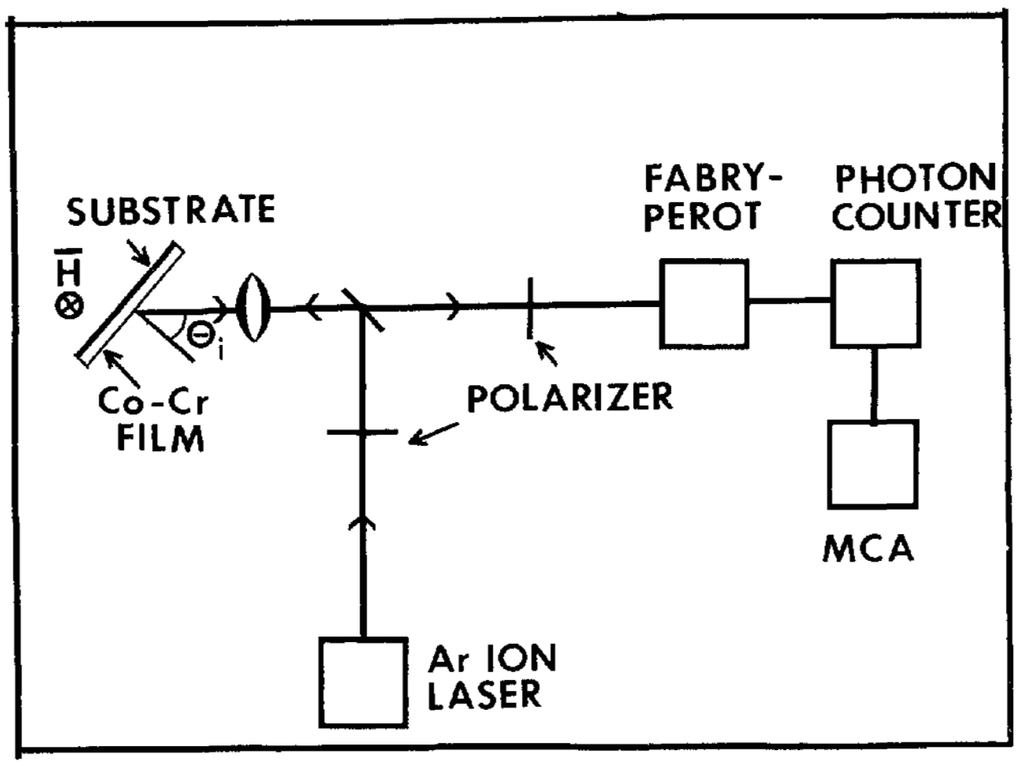

Fig. 1. Diagram showing the backscattering geometry for the Brillouin light scattering detection of thermal magnetic excitations in Co-Cr films.

The backscattering geometry used for the observation of magnetic excitations in Co-Cr films is shown in Fig. 1. The linearly polarized incident laser light (wavelength λ of 4880 Å) was focussed onto the sample at an angle θ_i to the film normal. Thermally excited spin waves in the material with some frequency ω interact with the incident light to produce scattered light which is frequency-shifted by $\pm\omega$. The backscattered light is analyzed with a multipass tandem Fabrey-Perot interferometer.[4] The Brillouin spectrum, i.e., the intensity of scattered light vs. frequency, was recorded using a multichannel analyzer (MCA). The static magnetic field H was applied parallel to the film plane and perpendicular to the incident light. The in-plane wave number $k_{//}$ for the magnon contributing to the scattering is controlled by θ_i,

$$k_{//} = 2k_i \sin\theta_i \qquad (1)$$

where k_i is the incident laser light wave number ($k_i = 2\pi/\lambda$). Typically, $k_{//}$-values from 2.2×10^4 cm^{-1} to 2.4×10^5 cm^{-1} are accessible.[5]

MAGNONS IN METAL FILMS

One would expect to observe scattering due to two kinds of magnetic excitations for metal films, surface waves and bulk spin wave modes. The surface magnon frequency ω_S for perpendicular propagation in an isotropic thin film is given by Damon-Eshbach (DE) theory,[6]

$$\omega_S^2 = \omega_0^2 + (\gamma 2\pi M_s)^2(1 - e^{-2k_S S}), \qquad (2)$$

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where $4\pi M_S$ is the saturation induction, γ is the gyromagnetic ratio, k_S is the surface magnon in-plane wave number (which corresponds to $k_{//}$ in the BLS experiment), S is the film thickness, and ω_O is zero wave number frequency limit at the top of the bulk spin wave band,

$$\omega_o = \gamma[H(H + 4\pi M_s)]^{1/2}. \quad (3)$$

The bulk magnon frequency ω_B for perpendicular propagation (in-plane field perpendicular to $k_{//}$) is given by

$$\omega_B^2 = \gamma^2(H + Dk_B^2)(H + Dk_B^2 + 4\pi M_s), \quad (4)$$

where D is the spin wave stiffness parameter. The k_B-parameter in Eq. (4) is the total bulk magnon wave number with contributions from k_x, the wave vector component perpendicular to the film for the standing spin wave mode, as well as the in-plane component $k_{//}$:

$$k_B^2 = k_{//}^2 + k_x^2. \quad (5)$$

In a thin film with no surface anistropy, k_x is quantized according to $k_x = n\pi/S$, with n = 1,2, ... The limited penetration depth for light in metal films, about 100 Å, leads to a spread in the perpendicular component of the light wave vector in the film. This leads to observable scattering from a series of bulk spin waves with different k_x values. The BLS results for both types of excitations in Co-Cr films are presented in the following sections.

EXPERIMENTAL RESULTS

A typical Brillouin spectrum is shown in Fig. 2. The data are for a 350 Å film with an in-plane applied field H = 250 Oe and an in-plane wave number $k_{//} = 1.3\times10^5$ cm^{-1}. This $k_{//}$ value corresponds to a θ_i-value of 30°. The BLS spectrum shows a single peak at -12.2 GHz and a pair of peaks at ±9.8 GHz. The peak at -12.2 GHz corresponds to thermal surface magnons which are propagating along the film surface with wave number $k_{//} = k_S$. The propagation for the surface magnons is nonreciprocal, so that the magnon peak appears on only one side of the central Rayleigh peak. When the direction of H is reversed, the propagation direction for the surface waves is also reversed and the magnon peak changes to the right side of the Rayleigh peak. This peak is labeled "S", for surface magnon. The magnon peaks at ±9.8 GHz are due to bulk spin waves with a wave number $k_B = [k_{//}^2 + (\pi/S)^2]^{1/2}$. These peaks are labeled "B", for bulk magnon. Due to the small penetration depth for the incident laser light, surface magnon scattering dominates over bulk magnon scattering and the S-peak intensity is stronger than that for the B-peaks.

The spectra for 100 Å films show surface magnon peaks on both sides of the Rayleigh peak, and no bulk magnon signal. In such thin films, two factors contribute to the apparent nonreciprocal surface magnon feature. First, the surface wave amplitude for the mode normally associated with the one surface is actually quite large at both surfaces, since the decay length $k_S^{-1} \approx 750$ Å is significantly larger than the film thickness. Second, the light penetrates the entire film, more or less, and samples the modes associated with both surfaces.

The reasons for the absence of bulk magnon peaks for 100 Å thickness are not clear. Such modes are also absent in very thin iron films.[5] In the case of sputtered Co-Cr, surface conditions or inhomogeneties may "wash out" the bulk magnons. This point requires further study. Bulk modes, as well as a surface mode, are clearly resolved for the 750 Å film. The larger thickness results in reduced k_x-values; three bulk modes are resolved on the scale of the spectra in Fig. 2.

MAGNON DISPERSION ANALYSIS

One objective of these experiments was to determine the magnetic parameters for the Co-Cr films using the BLS technique. This was accomplished by measuring

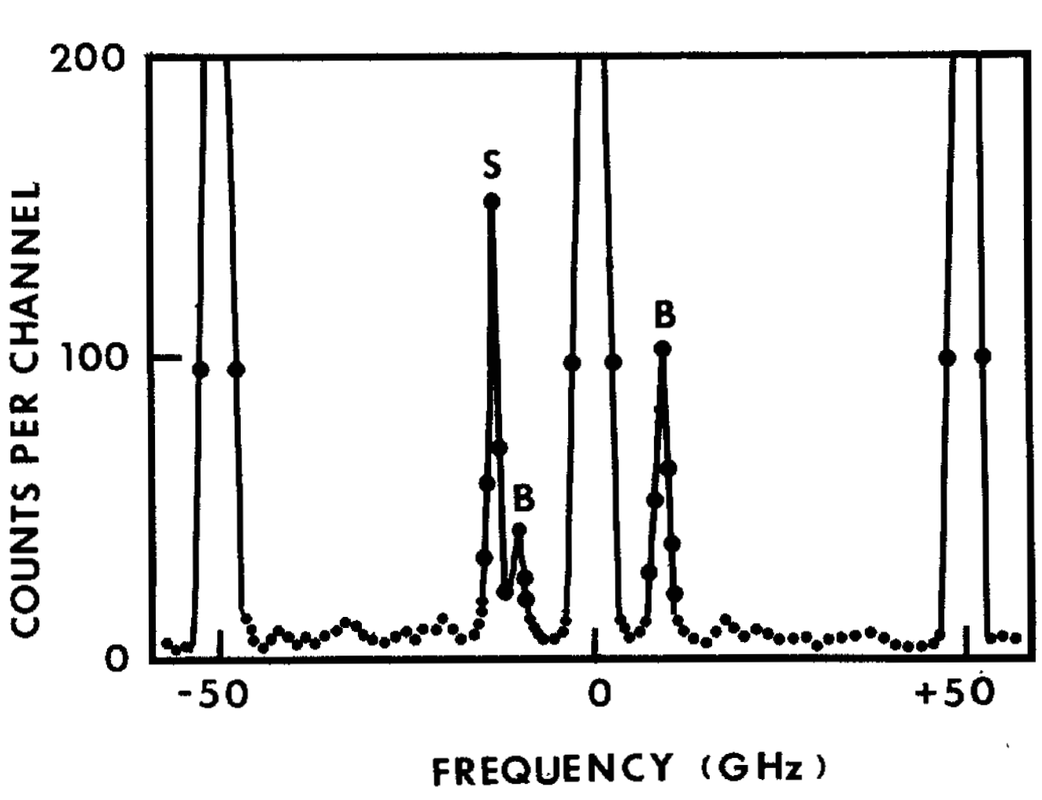

Fig. 2. Brillouin light scattering spectra for thermal surface (S) and bulk (B) magnon excitations in a 350 Å Co-Cr film.

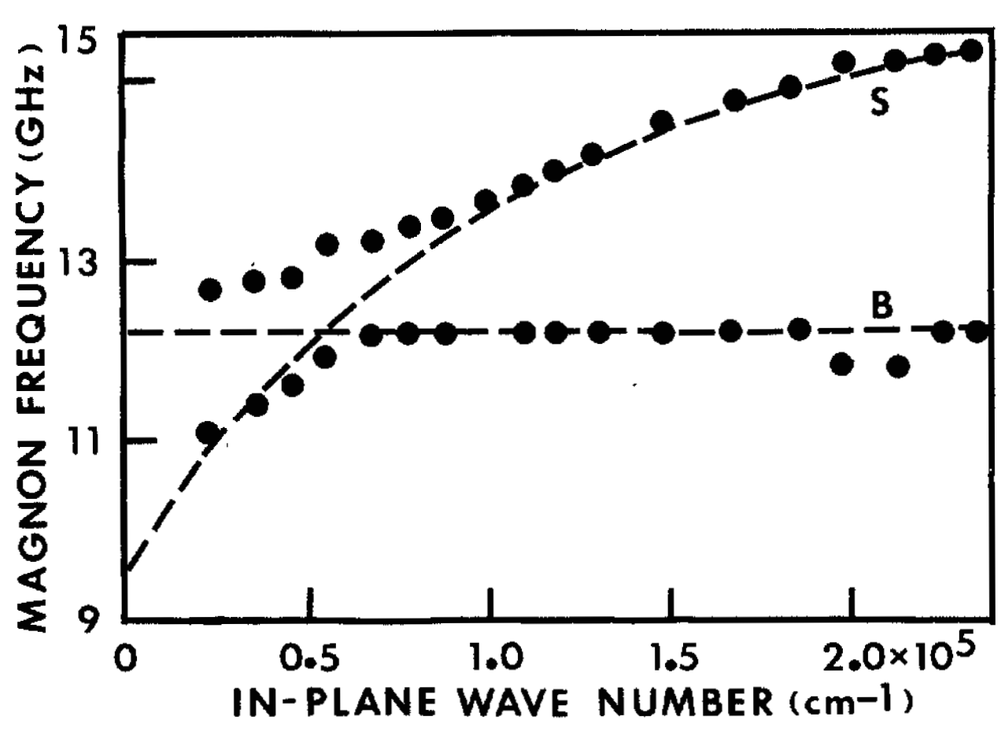

Fig. 3. Magnon dispersion results for the surface (S) and bulk (B) spin wave modes for the 350 Å Co-Cr film. The solid points indicate the data and the dotted lines represent theoretical curves as discussed in text.

the magnon dispersion, i.e., frequency vs. wave number, for the surface and bulk spin waves and fitting the data to theoretical expressions for ω_S and ω_B. The pertinent equations are somewhat more complicated than given above due to the perpendicular anistropy in the films.

Measured values of frequency vs. wave number for the 350 Å film and H = 1 kOe are shown in Fig. 3, along with theoretical curves for the surface (S) and bulk (B) magnon dispersions. A variation in θ_i of 5°-60° was used to step $k_{//}$ over the indicated range from 2.2×10^4 cm^{-1} to 2.3×10^5 cm^{-1}. The bulk magnon frequency is essentially wave number independent, as one would expect for the low values of $k_{//}$ accessible in the BLS technqiue. The surface mode shows the expected DE behavior. A clear repulsion between the two branches is observed near crossover, also as expected from theory.[7]

Table 1 summarizes the magnetic parameters which were obtained from fits of the theory to the data for all three thicknesses. Unlike ferromagnetic resonance (FMR) fits, surface magnon dispersion curve fits yield values for both the magnetization $4\pi M_S$ and the perpendicular anisotropy H_k. FMR can only yield the difference of these two quantities. BLS data also allow the determination of γ, the gyromagnetic ratio, and D, the spin wave stiffness parameter, which enters into the exchange field term (Dk_B^2) for bulk spin waves. A determination of D was not possible for the 100 Å film since no bulk magnons were observed.

Table 1. Magnetic parameters for Co-Cr films based on the Brillouin light scattering measurements.

Parameter	100 Å	350 Å	750 Å
γ (GHz/kOe)	3.0±0.1	3.1±0.1	2.7±0.1
$4\pi M_S$ (kG)	9.9±0.5	9.4±0.5	11.6±0.5
H_k (kOe)	0.9±0.1	1.0±0.1	0.6±0.1
D (Oe-cm^2)	---	$(7\pm1)\times10^{-10}$	$(7\pm1)\times10^{-10}$

The parameters given in Table 1 appear to be reasonable. The fitted γ-values of 2.7-3.1 GHz/kOe may be compared to 2.9 GHz/kOe for cobalt.[8] The fitted $4\pi M_S$-values are generally higher than expected for 82 at. % Co alloys. High $4\pi M_S$ values have also been reported on the basis of static magnetometry and torque data, and attributed to the possible segregation of chromium at grain boundaries.[9] The perpendicular anisotropy fields are small, as expected for large Co concentrations, and insufficient to produce an overall perpendicular anisotropy character with an easy axis of magnetization perpendicular to the film plane. The spin-wave stiffness parameter D for these Co-Cr films is about 7×10^{-10} Oe-cm^2, compared to literature values of 40×10^{-10} Oe-cm^2 for hcp Co[8] and 19×10^{-10} Oe-cm^2 for fcc Co.[10] These fitted D-values are a factor of five or so smaller than for iron or nickel.

CONCLUSIONS

This report has demonstrated the use of Brillouin light scattering to investigate magnons and magnetic parameters in ion-beam sputtered Co-Cr thin films. The BLS signals are strong, both surface and bulk magnons can be measured (fairly) easily, and the magnetic parameters appear to be reasonable.

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