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Brillouin light scattering study of Co/Cr/Co trilayers

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Abstract

Spin-wave excitations have been observed in Co(212 Å)/Cr(d_0)/Co(200 Å)/Si trilayers for $5 < d_0 < 35$ Å. Two modes, symmetric and antisymmetric, showed a frequency variation with applied in-plane magnetic field ($0.1 < H < 5.0$ kOe). The small frequency changes with Cr thickness at high and low fields indicate that exchange coupling is small. Values of $4\pi M_s$ typical of bulk values were obtained from fits to theory. No in-plane orientational frequency dependence was observed. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Brillouin light scattering; Co/Cr/Co; Trilayers; Exchange coupling

Magnetic coupling in magnetic/non-magnetic/magnetic trilayers continues to be of interest. Stray dipolar fields between neighbouring magnetic layers interact and for thin spacer layers exchange coupling occurs. The latter has been widely investigated since the discoveries of antiferromagnetic coupling [1] and oscillatory interlayer exchange [2].

Co/Cr/Co trilayers have received little attention [3] although both ferromagnetic and antiferromagnetic coupling have been observed. The present study examines the effect of Cr spacer thickness on the coupling, by observation of the spin-wave mode frequencies.

Brief details of the sample preparation are as follows. Growth was by electron beam evaporation in UHV on silicon (1 1 1) substrates with a thick amorphous SiO_2 surface layer giving rise to polycrystalline growth. The Co layers are nominally 200 Å thick as the top Co layer oxidises to a depth of 12 Å.

Brillouin light scattering measurements used a back-scattering geometry with the applied field in the plane of the sample and perpendicular to the incident light. An Argon ion laser operating at 5145 Å was used as the probe with the optical power at the sample being of the order of 250 mW. Measurements were carried out with a scattering angle of 45° corresponding to an in-plane magnon wavenumber of 1.73×10^5 cm^{-1} and two modes were detected. No frequency shift was detected for different in-plane orientations for any of the samples and the spin-wave frequency was measured as a function of the applied magnetic field H, where $0.1 < H < 5.0$ kOe for each sample. MOKE measurements indicated that most of the samples were saturated in fields of ~ 65 Oe although two required more than 100 Oe, the lowest applied field used here.

In the dipolar case where the effects of exchange are neglected and with no anisotropy the analytical solution for the spin-wave frequencies is given by [4]

$$\omega = \gamma[H(H + 4\pi M) + 4\pi^2 M^2(1 + 1/C)]^{1/2}, \quad (1)$$

where C is a constant. The two values of C can be found from the quadratic relation

$$C^2 \exp(-2k_{II}d_2) + C\exp[2k_{II}(d_1 - d_2)] - C\exp(-2k_{II}d_0) + C\,exp[-2k_{II}(d_2 + d_0)] + C\exp[2k_{II}(d_1 - d_0)] - C\exp[2k_{II}(d_1 - d_2 - d_0)] + C + \exp(2k_{II}d_1) = 0, \quad (2)$$

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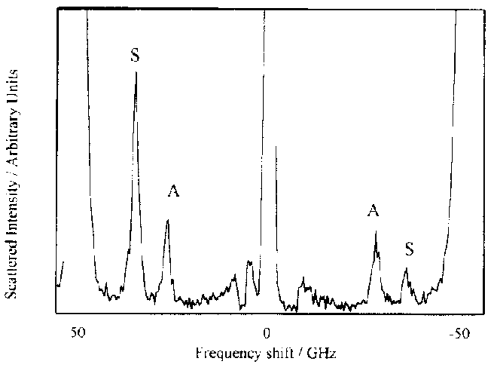

Fig. 1. Brillouin spectrum for Co/Cr/Co trilayer where $d_0(\mathrm{Cr}) = 35$ Å in a field of 2.0 kOe.

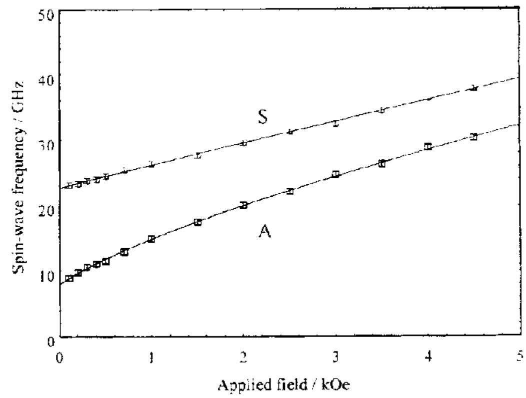

Fig. 2. Spin-wave frequency versus applied field for Co/Cr/Co trilayer where $d_0 = 35$ Å.

where $k_{//}$ is the in-plane magnon wavenumber, d_0 is the thickness of the spacer layer, and d_1 and d_2 are the thicknesses of the magnetic layers. The two modes at different frequencies are referred to as symmetric (S) and antisymmetric (A), which refers to the spin-wave amplitudes in the two magnetic layers being parallel (S) or antiparallel (A). A typical spectrum is shown in Fig. 1 for $d_0 = 35$ Å, where the two modes are observable on the Stokes and anti-Stokes sides of the spectrum.

The results of the measurements of the spin-wave frequency versus applied field are shown for the film for which $d_0 = 35$ Å in Fig. 2. The solid lines represent fits to Eq. (1) for the two values of C. For the A mode γ, $4\pi M_s$ and C were all used as variables but the S mode required the calculation of C to obtain realistic values for γ and $4\pi M_s$. Results of the fits are shown in Table 1.

For all samples the value of γ lies in the range 2.95–3.08 GHz/kOe which corresponds to a g-value of 2.1–2.2. The values of $4\pi M_s$ are all of the order of ~ 17 kG which compares favourably with the bulk value of 17.6 kG. The fitted value of the constant C is generally of the same order of magnitude as the calculated values. Any disparity probably arises from a lack of precision about the real thickness of the layers, since Co and Cr alloy. However, no general trend was observed for different spacer thicknesses.

In dipolar coupled layers anti-parallel alignment of the spin-wave amplitudes is favoured and the A mode is the lower frequency mode. It has been shown [5] that exchange coupling modifies only the frequency of the A mode. As the spacer thickness is reduced, the frequency of the exchange affected A mode increases, and may become higher than the S mode.

The results of the measurement of the spin-wave frequency versus Cr spacer layer thickness at various

Table 1
Values of gyromagnetic ratio γ, saturation magnetisation $4\pi M_s$ and constant C for different Cr thicknesses d_0.

Crd_0(Å)	Mode type	γ(GHz/kOe)	$4\pi M_s$(kG)	C(calc)	C(fitted)
5	S	3.01	17.23	0.7576	—
	A	3.04	16.85	5.85×10^{-3}	7.06×10^{-2}
10	S	3.01	17.33	0.7562	
	A	2.98	17.52	1.16×10^{-2}	1.02×10^{-2}
15	S	3.02	16.88	0.7548	
	A	2.92	18.34	1.73×10^{-2}	4.96×10^{-2}
20	S	2.98	17.64	0.7534	—
	A	2.96	17.75	2.29×10^{-2}	6.09×10^{-2}
25	S	2.89	18.80	0.7520	
	A	2.95	18.36	2.85×10^{-2}	6.51×10^{-2}
30	S	3.02	17.52	0.7506	—
	A	3.02	16.67	3.45×10^{-2}	8.95×10^{-2}
35	S	3.08	17.03	0.7492	—
	A	3.08	15.74	3.94×10^{-2}	1.06×10^{-2}

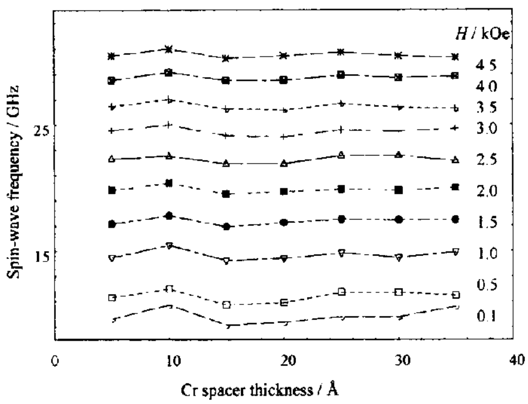

Fig. 3. Spin-wave frequency versus Cr thickness d_0 for applied fields 0.1–4.5 kOe.

applied fields are shown in Fig. 3 for the A mode and a similar plot was obtained for the S mode. Only small changes in the frequencies were observed with the possible exception of the A mode at $d_0 = 10$ Å which shows the largest variation. The variation was consistent at all fields.

For exchange coupled layers one expects larger variations at small spacer thicknesses, and variations with larger magnitudes than those observed here. For example a 2 GHz spin-wave frequency variation was observed by BLS in Co/Ru multilayers for spacer layer thicknesses in a similar range [6]. On the basis of the current observations the neglect of exchange coupling is justified. The samples were crystalline showing no texture and it was therefore expected that the anisotropy would be small. The fact that no variation of spin-wave frequency was found at different orientations verified this assumption.

In conclusion, the effect of exchange coupling is small and films of intermediate thicknesses and below $d_0(\mathrm{Cr}) = 10$ Å in particular are needed to quantify such effects. The dipolar approach is a useful starting point for the analysis of the spin-wave frequencies in these films and the values of $4\pi M_s$ deduced are consistent with bulk values.

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