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Brillouin Scattering from Magnetic Excitations in Coupled Layered Systems and Dots

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where M is the magnetization, γ the gyromagnetic ratio (2.93 GHz/kG for Fe), D is the spin wave stiffness constant, n an integer (1,2, . . .), and L the slab thickness. Note that the FMR frequency corresponds to n = 0. Also observed is the 'surface' magnon at a frequency

$$\omega^2 = \gamma^2\{H[H + 4\pi M] + (2\pi M)^2[1-\exp(-2qL)]\} \qquad (2)$$

where q is the wavevector determined by the scattering geometry. Note that for q = 0 Eq. 2 also yields the FMR frequency.

In the limit of very thin films (L < 100Å) it can be shown that all the frequencies predicted by Eq. 1 lie outside the frequency range probed by Brillouin scattering; these modes will therefore not be considered further. All modes in systems consisting of very thin layers can therefore be viewed as arising from the interaction of a mode described by Eq. 2 in each layer, the frequency of these modes is given by the FMR frequency with a perturbation due to the finite wavevector. In uncoupled magnetic superlattices the dynamic interaction between these modes gives rise to the, now well understood[3, 4] band of modes and the unusual properties of the surface magnon. It is worth noting that because Eq. 2 is a small perturbation to the FMR mode, it is valid in zeroth order, to treat the resonance of each layer as that of a giant spin in which the whole layer precesses in phase. This conceptual simplification enables the complex systems to be discussed below to be viewed in a simple albeit qualitative picture. The complete quantitative description is of course important when extracting the magnitude of the various relevant parameters.

During the past few years the magnetic coupling of magnetic layers separated by a non-magnetic spacer has attracted great attention mainly due to possible technological applications of the resulting giant magnetoresistance. It is interesting that coupling across nonmagnetic layers was first observed using Brillouin scattering by Grünberg[7] long before giant magnetoresistance was discovered. The coupling between magnetic films has been phenomenologically identified as bilinear and biquadratic corresponding to terms J_1 $(M_1{*}M_2)$ and J_2 $(M_1{*}M_2)^2$, respectively, in the energy. The origin of the bilinear coupling is now believed to stem from RKKY type oscillations in the spins of the spacer layer; it gives rise to ferromagnetic or antiferromagnetic (AF) alignment between neighbouring layers. The origin of biquadratic coupling is still being debated, it gives rise to 90° alignment of the layers. Independent of their origin these new terms introduce a host of novel magnetic phenomena.

In antiferromagnetically bilinearly coupled superlattices it has led to the first observation of a surface instability predicted decades ago[8]. The field-induced rearrangement of the magnetization of the near-surface layers, called a surface spin flop, leads to a complex mode structure which we investigated with Brillouin scattering from Fe/Cr superlattices.[9] Experimental spectra will be presented and compared with calculations. However, although they can be qualitatively reproduced theoretically, their complexity do not allow the physical parameters to be reliably extracted.

The complexities associated with the use of Brillouin scattering to extract quantitative values of the magnetic parameters will be illustrated with a study of bilayers of Fe/Cr/Fe.[10] Typical mode frequencies obtained by Brillouin scattering are shown in Fig 2, the symbols are measured frequencies and the full lines are the result of fitting procedures. Emphasis will made on the error determination of the parameters obtained.

The final example is the magnetization and resonance frequencies of arrays of submicron Fe magnetic dots investigated using Brillouin light scattering (BLS) and Magneto-Optic Kerr Effect (MOKE). A crucial issue in these systems is the possibility of coupling between the dots. We have investigated inter-dot coupling by studying the effect of the symmetry of the dots arrays. BLS measurements on square and hexagonal Fe arrays showed substantial two-fold anisotropies, inconsistent with these array symmetries. By fabricating dots with different aspect ratios we find that a large anisotropy can be induced along the long axis of the dots which may not coincide with the array axes. This anisotropy leads to clear two-fold anisotropy patterns in the angular dependence of the Brillouin frequencies as is shown in Fig 3. The presence of anisotropy was confirmed using MOKE; Fig. 4 shows the magnetization loops measured along the long (easy) and short (hard) axes.

The field dependence of the magnetic resonances observed by BLS are fully explained by treating the observed modes as the resonances of isolated ellipsoids.[11]

$$\omega^2 = \gamma^2\{ [H+4\pi(N_y-N_z)M] [H+4\pi(N_x-N_z)M] \} \quad (3)$$

where N_i (i = x, y, z) are the appropriate demagnetizing factors. In Fig 5 the experimental BLS results for circular dots and for elliptical dots with the field along the hard and easy axes are shown. The full lines are fits to Eq. 3 and the resulting demagnetizing factors are consistent with those predicted by shape anisotropy theory.[12]

We conclude that, although interdot coupling may be present, its magnitude is below the accuracy of the present experiments. This conclusion contrasts with that found in Refs. 13 and 14 where the BLS results were interpreted as an indication of interdot coupling; possible origins of the discrepancy will be discussed.

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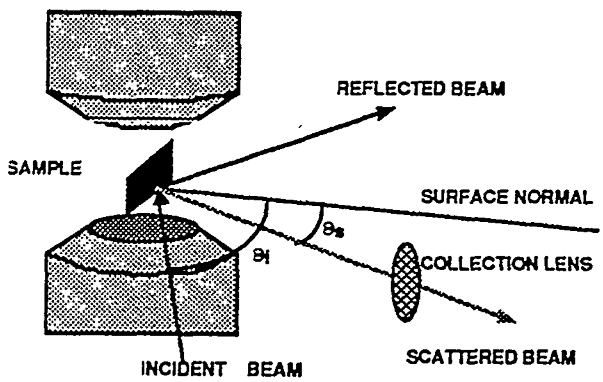

Fig 1 Scattering geometry utilized in Brillouin experiments.

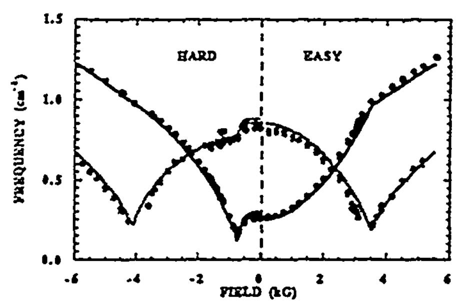

Fig .2 Brillouin frequency shifts from a (100) oriented Fe/Cr/Fe trilayer for the field applied along the hard and easy axes.

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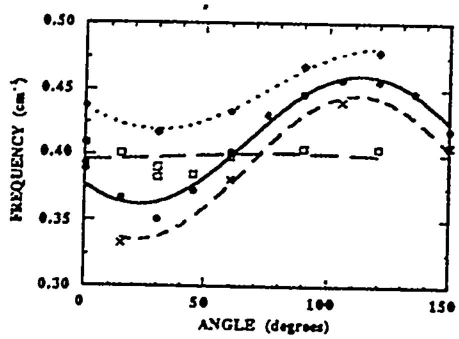

Fig. 3 Angular dependence of the magnon frequencies in a field of 1 kG. Open squares are for circular dots, other symbols are for dots with aspect ratios in the range 0.75 to 0.80.

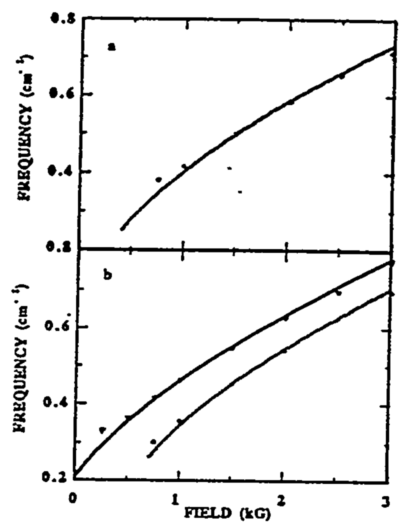

Fig 5 Field dependence of magnons for (a) circular and (b) elliptical dots with the field along the easy and hard axes. Symbols are experimental data, lines are fits using Eq.3

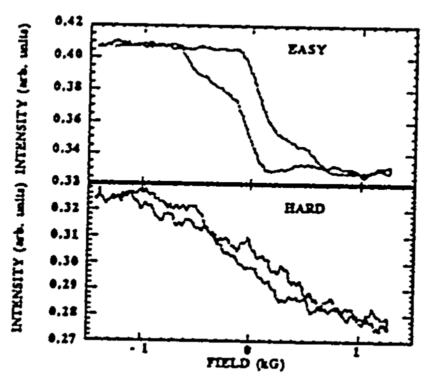

Fig. 4 Kerr loops for a sample of elliptical dots with the field along the easy and hard axes.