SUPERLATTICE MAGNONS

A powerful technique for optimizing material properties is to deposit alternating layers of different materials to form a thin film superlattice. In particular, magnetic and non-magnetic materials grown as a superlattice exhibit a variety of tunable couplings between the magnetic layers. Control of these couplings by varying the layer materials and thicknesses has lead to dramatic increases in performance in certain device applications. A prime example is the recent use of layered magneto-resistive films in high-performance magnetic recording heads and sensors. The inter-layer magnetic coupling can survive across as many as 30 non-magnetic atomic planes due to its one-dimensional nature, but the coupling strength is always much weaker than bulk material magnetic interactions.

The behavior of the magnetic fluctuations (magnons) in these weakly coupled layer systems is of interest because it provides a direct measure of the magnetic interactions responsible for the magnetic structure, and leads to a better understanding of the unique layer to layer couplings. Until now, the only measurements that have probed these fluctuations have used Brillouin light scattering [1], or ferromagnetic-resonance techniques [2], both of which measure only the longest wavelength dynamics. These measurements have found interesting resonances associated with the superlattice structure.

It is important to directly measure the magnons at shorter wavelengths in order to determine the dispersion, which directly relates to the magnetic interactions, both within and between layers, and whether or not the magnetic fluctuation waves propagate between layers. Only inelastic magnetic scattering techniques can provide this information, but with current neutron scattering sources the intensities from such measurements can be prohibitively low, because the amount of magnetic material in the films is so small.

In order to overcome this difficulty we have made neutron inelastic scattering measurements on a very large superlattice of alternating layers of dysprosium and yttrium. Dysprosium is the magnetic constituent, and it has the strongest neutron magnetic-scattering of all the elements. In order to maximize the amount of Dy, 350 bilayers composed of 43 Å of Dy and 28 Å of Y (designated [Dy$_{43}$/Y$_{28}$]$_{350}$) were grown by MBE techniques on a 2.5 cm x 1.3 cm substrate resulting in 3 mg of Dy in the sample.

The magnetic structure of this superlattice has previously been determined to be the basal-plane helical structure of bulk

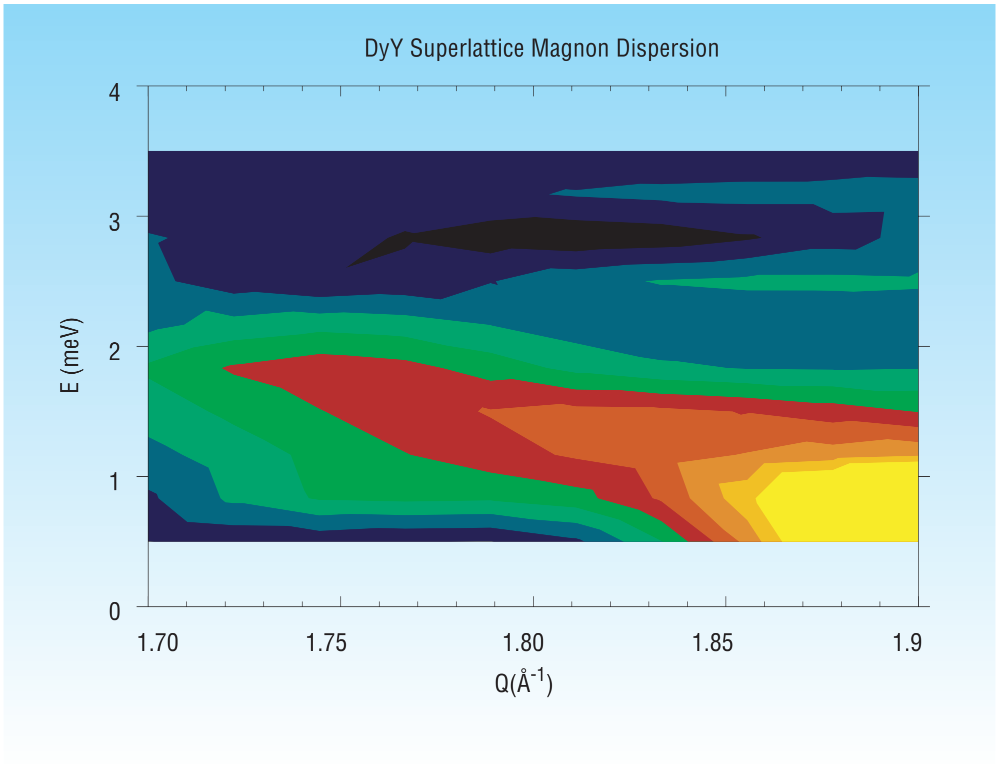

FIGURE 1. Inelastic magnetic scattering from a [Dy$_{43}$/Y$_{28}$]$_{350}$ superlattice, obtained by subtracting 10 K data from 75 K data, shown as an intensity map in Q-energy space. The highest intensity is 300 counts/ 30 min and decreases by 30 counts for each level. A magnetic Bragg peak is just off the graph at Q = 1.97 Å^{-1}.

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Dy with a coherence length greater than 4 bilayers. The helix progresses remarkably undisturbed through the conduction electrons of the non-magnetic yttrium, but with a turn-angle that is different than in the dysprosium. The coupling strength across the yttrium has been measured by applying a uniform external magnetic field. The coupling breaks down when the external field provides 0.2 meV per Dy atom in the basal-plane, while the equivalent zone-boundary magnetic fluctuation in bulk Dy is greater than 5 meV per Dy atom.

The inelastic neutron scattering measurements were performed at the NIST Center for Neutron Research on the cold-neutron spectrometer SPINS. A multi-component crystal was used to analyze the energy of the scattered neutrons in order to enhance the measured intensity while sacrificing wave-vector (Q) resolution. Measurements were performed at 75 K as a compromise between the size of the ordered magnetic moment and the thermal population of magnons. The magnons of interest are those propagating along the superlattice growth direction or the c-axis of the hcp rare-earth structure. Lower magnon energies produce higher thermal populations, but become contaminated with elastic background scattering, so it is necessary to subtract scans taken at low temperatures where the magnons have become depopulated in order to remove this background. The resulting magnetic signal is shown in Fig. 1 as a color-coded intensity map in Q-energy space. There is a clear ridge of intensity which moves to higher energies as Q moves away from the magnetic Bragg peak at 1.97 Å^{-1}. We have concentrated on the magnon branches that extend towards smaller Q since they move away from the intense magnetic and nuclear Bragg peaks that produce a large elastic background. This measured dispersion is compared with bulk Dy in Fig. 2, which also shows the diffraction pattern along the growth direction (c-axis) of the superlattice. The bulk Dy dispersion is shown as lines originating from the magnetic Bragg peaks at Q = 1.97 Å^{-1} and Q = 2.06 Å^{-1}. The measured magnons are shown as bars centered on the measured peak positions and with lengths representing the full-width-at-half-maximum-intensity. The agreement with the bulk dispersion is quite good. There is no evidence in these data of the influence of the yttrium layers other than possibly the splitting of the dispersion into two branches because of the superlattice structure as shown by separate bars at both Q = 1.8 Å^{-1} and at Q = 1.75 Å^{-1}. The observed modes are not over-damped, but we cannot measure the damping under the current experimental conditions. Also, these data would have to be extended to smaller Q, in order to approach the interface thickness. We are currently designing additional focusing configurations so that the instrumental resolution will be better optimized for measurements of this dispersion surface.

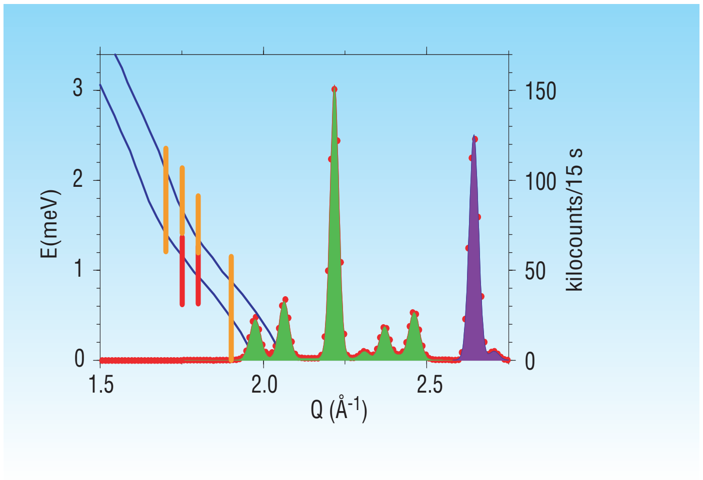

FIGURE 2. The dispersion along the growth direction (c-axis) measured for the $[\mathrm{Dy}_{48}\mathrm{Y}_{23}]_{350}$ superlattice is plotted against the energy scale on the left side. It is compared to the measured dispersion in bulk dysprosium (solid lines) expected to originate from each of the superlattice magnetic Bragg peaks. (Only the negative Q branches from the two low Q Bragg peaks are shown). On the right side the diffraction scan for this sample showing the superlattice peaks is displayed. This film is so large that the sample diffraction peaks are as strong as the substrate peak shown in blue on the right.

REFERENCES

[1] B. Hillebrands and G. Güntherodt in *Ultrathin Magnetic Structures I + II*, edited by B. Heinrich and J. A. C. Bland (Springer Verlag, 1994).

[2] C. F. Majkrzak et al., Adv. in Phys. **40**, 99 (1991).