SPIN-WAVE IN LAYERS AND HETEROSTRUCTURES

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There is a renewed interest raised on diluted magnetic semiconductors, because of potential applications in the field of spintronics. These systems are basically obtained by the substitution of cations by Mn^{2+} in semiconductors based on II-VI compounds. They have the zinc blende (ZB) structure, and present magnetic properties depending on their composition. Superlattices obtained by sandwishing magnetic layers and non-magnetic spacers may be obtained in a large range of composition and thickness.

The understanding of the magnetic properties of these systems have given rise to a lot of experimental and theoretical works. An appealing suggestion is to measure the spin-wave dispersion of a parent compound (MnS, MnSe, or MnTe) to deduce the dominant exchange interactions and anisotropies. Unfortunately, these compounds have no stable ZB structure and only recently, molecular beam epitaxy (MBE) gave the opportunity to get ZB MnTe as a pure system or as layers inside heterostructures. This means quite small available sample volumes, but the progressess realized on triple-axis spectrometers (TAS) allowed us to carry out spin-waves measurements on such systems, as reported here.

MBE-grown MnTe

Below $T_N \approx 65$ K, MnTe becomes a type-III antiferromagnetic (AF) [1]. This is expected in face-centered-cubic magnetic compounds when dominant nearest and next-nearest neighbors exchange are both antiferromagnetic.

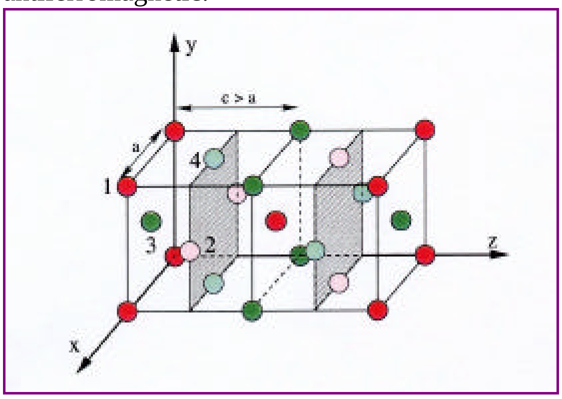

Figure 1. Magnetic structure of AF-III MnTe. Only positions of magnetic Mn atoms are shown. Spins **1** and **3** are antiparallel, as are spins **2** and **4**. When the structure is collinear, spins **1** and **2** are parallel, while in the non-collinear structure proposed by Keffer spins **1** and **2** are perpendicular.

The magnetic transition is of first order and associated to a tetragonal lattice distortion, with c > a. The magnetic cell may be defined as a body centered tetragonal cell, with a doubling of the nuclear cell along c. As seen on figure 1, the structure consists of a stacking of AF planes perpendicular to the c axis, with an arrangement such as A B -A -B. The existence of equivalent axes for the elongation leads to nuclear and magnetic domains. The strain due to may the mismatch between the MnTe layer and the buffer layer (ZnTe or CdTe) interposed on the GaAs substrate, yields inequivalent domain populations.

Several issues have been addressed concerning the magnetic properties of ZB MnTe: 1) Collinearity of the structure: Taking a Mn moment of an A plane, the resultant interactions of the Mn moments of the B planes is null. Hence, any canting angle between sublattices A and B is allowed, up to 90 degrees as proposed by Keffer for β-MnS. 2) Exchange interactions: all exchanges are super-exchanges via Te anions. Theoretical calculations suggest that distant neighbors up to the fourth ones should yield significant contributions. 3) Anisotropy: a single-site anisotropy should be present to force the spin direction in the plane. But no significant dipolar terms are expected. Moreover, the non-centrosymmetry of the structure allows anisotropic exchange, such as the Dialoshinski-Moriya exchange, so inter-site anisotropy has to be considered.

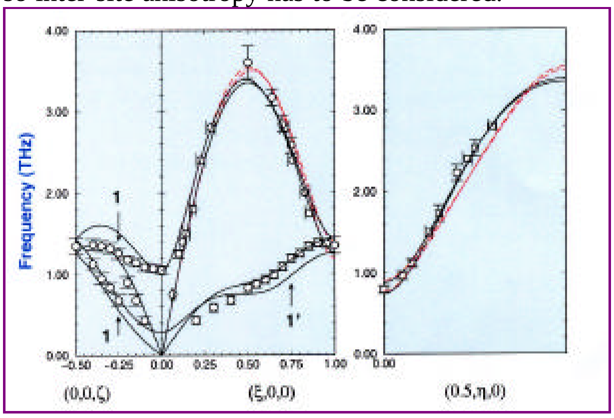

Figure 2. Spin-wave modes of MnTe measured at T ≈ 15 K, with calculated curves discussed m Ref. 2.

Samples, up to 6 μm thick, have been obtained at the Institute of Physics of Warsaw (Poland). With a surface of about 3 cm^2, this corresponds to a sample volume of about 1.8 mm^3, but the maximum volume of a magnetic domain was about 0.7 mm^3.

Inelastic neutron scattering measurements have been carried out on the former 1T TAS (before its move on 2T) and on the new 2T design. The dispersion measured at low temperature are reported in Fig. 2, together with calculated curves deduced from a model Hamiltonian used to describe the system. Details on the measurements and the data analysis may be found in Ref. 2.

The main conclusions may be summarized as it follows: 1) The observed spin-wave dispersion is only compatible with a collinear or a very weakly canted structure. 2) Exchange interactions up to the fourth neighbours have to be considered and numerical values have been deduced from the measurements. 3) A planar single-site anisotropy may account for the spin-wave gap at the origin, but induces a mode-splitting along the Brillouin zone, too large when compared to the experiment (see Fig. 2). 4) A Dzialoshinski-Moriya term does not provide a good answer to describe the inter-site anisotropy. Anyhow such an anisotropy is clearly needed for a better account of the experimental results.

Furthermore an unusual damping, illustrated on Fig. 3, has been observed when increasing the temperature. The explanation of such a behavior is still to be found. It might be a consequence of the large frustration inherent to the type-III AF structure when departing from its fundamental state, or to an unusal coupling with the crystalline lattice, as all magnetic exchanges are mediated by Te cations.

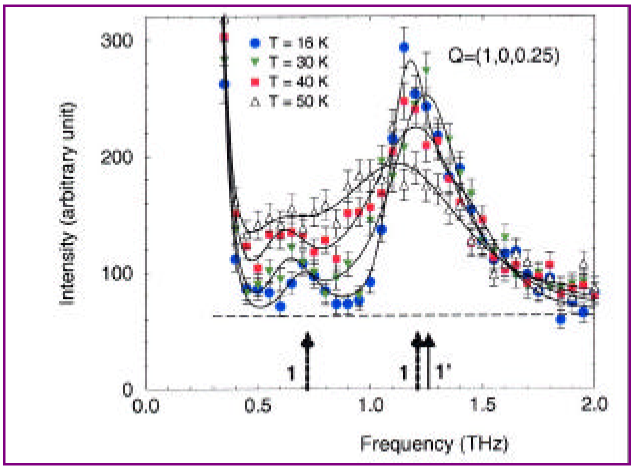

Figure 3. Temperature dependence of the scattering measured at Q=(0.25,0,1). Domain effects superimpose points **1** and **1'** marked in Fig. 2.

MnTe/ZnTe superlattices

At low temperature, each MnTe layer still presents the AF-III structure. A long-range coherence between MnTe layers, through the non-magnetic spacer, is observed up to a ZnTe thickness of about 20 Å. This is not expected for this kind of hetero-structure. Superlattices MnTe(m)/ZnTe(n), where m and n are the number of monolayers in a layer, have been provided by the Institute of Physics of Warsaw. Two series, with m=15 and n=3,4, or 5 and with m=20 and

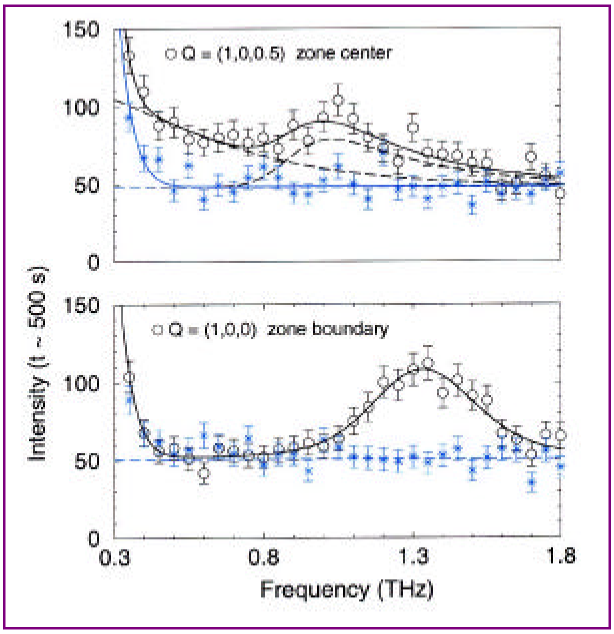

Figure 4. Zone center (top) and zone boundary (bottom) measurements evidencing spin-wave excitations in MnTe(20)/ZnTe(6). Star symbols correspond to background measurements obtained after a 90 degrees rotation of the sample.

n=4,6,8, or 10, have been investigated. Diffraction measurements confirmed a coherence up to ≈ 1200 Å for the 15-3 sample, but still of ≈ 350 Å in the 20-6 sample, the interlayer distance being ≈ 3.2 Å. The most surprising is that this coherence implies the preservation of the phase between MnTe layers through the non-magnetic ZnTe layers, whatsoever the number of monolayers in the layers. The thickness of about 1 μm of the samples corresponded to an overall magnetic volume of about 0.25 mm^3. On the new 2T TAS, we nevertheless succeeded to observe the spin-wave modes in the Q-direction corresponding to a propagation along the stacking axis of the superlattice. Measurements at the zone center and boundary are reported in Fig. 4. Magnetic excitations have been observed in the whole intermediate range. Their analysis is in progress.

References

[1] T. M. Giebultowicz, P. Klosowski, N. Samarth, H. Luo, J. K. Furdyna, and J. Rhyne, Phys. Rev. B **48** (1993) 12817.
[2] B. Hennion, W. Szuszkiewicz, E. Dynowska, E. Janik, and T. Wojtowicz, Phys. Rev. B **66** (2002) 22442