Magnetic fluctuations and the thermoelectric effect

I summarise recent work on IrMn films, where varying the thickness of the films can lead to very large values of the Seebeck coefficient at room temperature, understood as the coupling of the conduction electrons to critical magnetic fluctuations. Comparison of the critical anomaly with different capping layers allows us to quantify the contribution of fluctuations. I also discuss work completed during my visit to the IMR on the magnetic structure and dynamics of magnetic umbrella states in rare-earth iron garnets, a class of materials becoming prominent for spintronics applications.

One purpose of my visit was to develop the subject of magnetic fluctuation induced thermoelectric effects. This was following the discovery in the group of Haiming Yu in Beijing of a giant tunable value of the Seebeck coefficient in layers of IrMn (Sa Tu et al, Nature Commun., 2020) Theoretical calculations had given predictions for the shape of the anomaly in terms of critical fluctuations close to a size dependent ordering temperature (P. Wolfle and T.Z., PRB 2021). During my visit to Sendai I had video meetings with the Beijing group and S. Maekawa at Riken to compare specific predictions of the theory with the measured temperature dependence of the Seebeck coefficients. In particular to understand the difference between samples with and without a capping layer of CoFeB (see Figure!). While the sample capped with CoFeB gives nice agreement with the theory, especially including two-dimensional fluctuations, the uncapped sample has a much weaker anomaly, because of a larger cutoff, implying a smaller Landau damping parameter. In the future, we should relate the fitted parameters to microscopic parameters of the interface, for example Rashba fields.

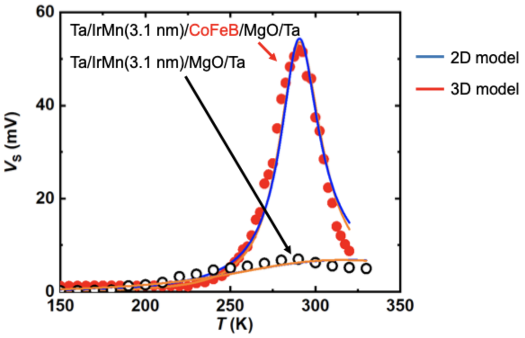

Fig.1 A fit to the critical fluctuations on the experimental thermopower in an optimised IrMn layer capped with (upper curve) and without (CoFeBN)Hancheng Wang, Haiming Yu *et al* unpublished 2022)

While in Sendai I learned of the remarkable work on thermoelectric effects by S. Okamoto in certain crystalline samples of the metallic alloy Fe_xAl_{1-x} in the group of Prof. T. Itchisubo. While it seems that the magnetic fluctuations are probably not crucial to the thermoelectricity here, the magnetic properties of these alloys are interesting in themselves and should be investigated in the future.

During my time visiting the IMR I took the opportunity to develop a theory on the family of Rare-Earth Iron Garnets, materials that have been long known, but are emerging as an important class of insulators that can be used in spintronics. In particular when the rare-earth atoms bear magnetic moments, they are known to form non-collinear magnetic "umbrella" structures. The question is to understand the origin of these structures and their influence on the dynamics, especially the chiral dynamics, crucial to spin injection in devices. We have proposed (Reference [1]), a simplified model Hamiltonian involving magnetic exchange between the highly anisotropic rare-earth and the iron moments forming a ferrimagnetic Iron lattice. The key point is that the crystal structure of the materials leads to triples of mutually orthogonal easy axes for the local strong rear earth anisotropy, and when exchange coupling is included with the relatively weakly anisotropic Fe moments, this naturally leads to a magnetic umbrella structure. In fact when both easy- and hard-axes are considered, it can lead to a "double umbrella phase). In a simplified model of the structure, solved in mean field theory, this gives a good account of the measured canting angles in TbIG as extracted from previous neutron diffraction at different temperatures (see Figure 2, upper panel) but predicts, contrary to the older measurements a continuation of canting above the compensation temperature. This prediction, as well as small induced canting on the iron d-sites, remains to be tested in future diffraction experiments. With this simple model in hand, we could proceed to predict the effects on the dynamics [1]: the gapping of the accoustic mode, by hybridization of the crystal field levels of the rare earth and the spin deviations on the iron. Most importantly for future spin-pumping experiments we can also predict more complex behaviour of the chirality of the accoustic modes (see Figure 2, lower panel). This was stimulated by the inelastic neutron studies carried out in Grenoble and currently also in the group of Prof. M. Fujita. While in Sendai I initiated further detailed theoretical analysis with M. Mori (JAEA) with whom we wish to compare in more detail with the experiments.

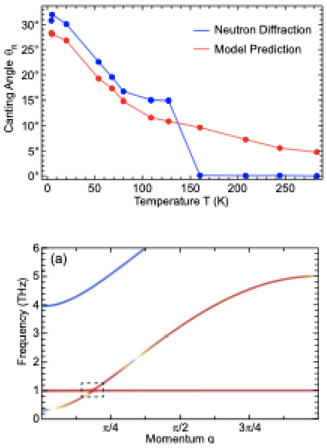

Fig.2 (Upper figure) A comparison of the calculated canting angle of the magnetic umbrella for TbIG (in red) with the values measured by neutron diffraction. A prediction of the theory is that canting should continue above the magnetic compensation point. (From Reference [1] Figure 6)

(Lower panel) Our calculated low energy excitations in a simplified lattice model with the chirality coded in colour (red and blue for the oppositely polarized modes of pure chirality) In contrast to the ferrimagnet YIG, where the rare-earth element has no magnetic moment, hybridization of the rare earth moment, with strong spin-orbit coupling leads ocal crystal field levels, leads to a gap and rather complex chirality of the original accoustic mode. (From Reference [1] Figure 4a).

References

[1] B. Tomasello, D. Mannix, S. Gepraegs, T. Ziman. Annals of Physics (in “Selected topics in condensed matter theory: in memory of Igor Dzyaloshinskii” in press, 2022)

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