Investigation of Insulator Spintronics and the Spin Seebeck Effect in Ferroic Compounds

Information transport and processing by pure magnonic spin currents in insulators is a promising alternative to conventional charge-current driven spintronic devices. The absence of Joule heating as well as the reduced spin wave damping in insulating ferromagnets has been suggested to enable the implementation of efficient logic devices. During the stay at ICC-IMR, magnetization orientation dependent spin signal detection in collinear magnetic multilayers with spin transport by magnonic spin currents was studied. We found in $Y_3Fe_5O_{12}$ | CoO | Co tri-layers that the detected spin signal depends on the relative alignment of $Y_3Fe_5O_{12}$ and Co. This demonstrates a spin valve behavior with an effect amplitude of 125% in our systems. Furthermore we also worked on topological spin structures leading to a joint high impact publication.

In Fig. 1 (a) the YIG/CoO/Co multilayer sample is schematically shown [1]. After determining the switching properties of both YIG and Co, we study next the measured spin signal as a function of alignment of the YIG and Co layer. Fig. 1c-f shows field-dependent voltage signals generated in sample A at T = 120K induced by f = 4.5 GHz microwave irradiation. By the application of specific field sweep sequences, parallel (d, e) as well as anti-parallel (c, f) alignment of YIG and Co is rea-lized. In the parallel state (Fig. 1d,e) a multi-peak voltage signal appears. It is well fitted by two overlapping Lorentzian line shapes of opposite sign, slightly shifted peak fields, and different line widths. The antiparallel state (Fig. 1c,f), on the other hand, exhibits a voltage peak of one polarity but with a significant asymmetry, which can be fitted by two overlapping Lorentzian functions. The comparison of all four datasets allows us to both separate and attribute the peaks to different effects. Depending on the individual orientation of YIG and Co, the peaks change sign separately and thus can be identified as (i) the signal of the spin current generated by spin pumping from the YIG, transmitted across the CoO and detected by the ISHE in the Co (blue curves in Fig. 1c-f) and (ii) a second signal that depends only on the Co layer direction and thus originates from the Co (green curves in Fig. 1c-f). For the latter possible explanations are a thermally induced ANE signal or spin rectification (SR).

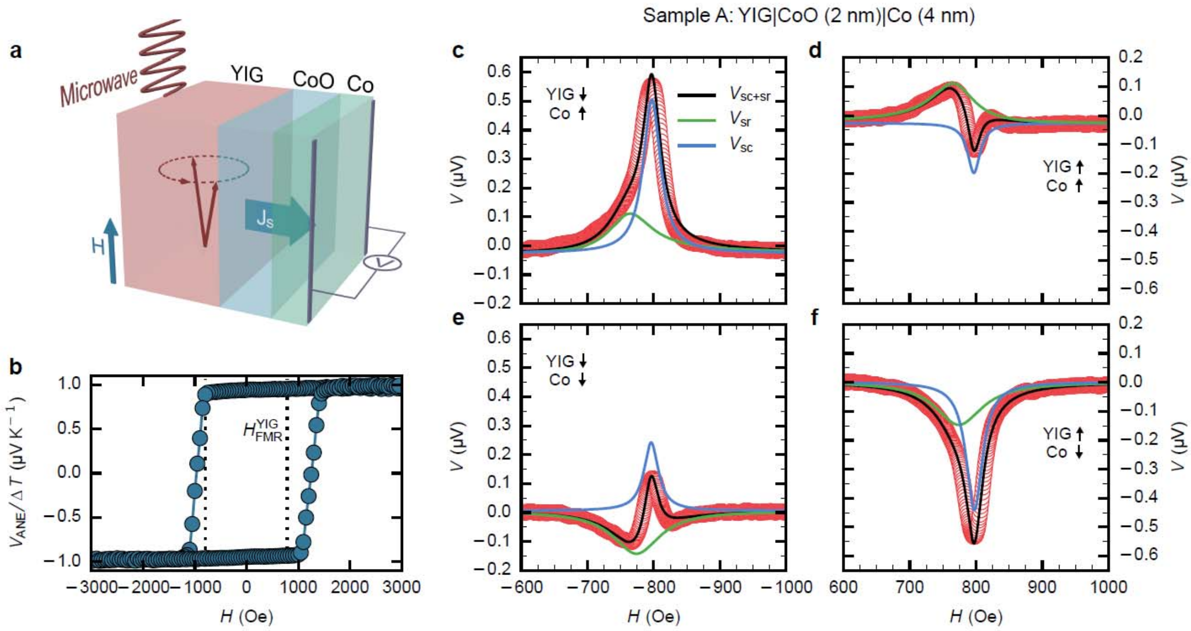

Fig. 1 (a) Illustration of the investigated YIG | CoO | Co tri-layer system. A spin current J_s induced in the YIG by FMR spin pumping propagates through the CoO intermediate layer and is detected electrically in the Co layer via the ISHE. The relative magnetization orientation of YIG and Co can be adjusted to be either parallel or antiparallel. (b) Typical ANE hysteresis loop observed at T = 120 K, being field cooled at H_{ext} = 90 kOe. (d)-(f) Field-dependent voltage signals detected in sample A induced by microwave irradiation. The total signal is given by a superposition of two distinct signals V_{sc} and V_{sr}, the sign of which individually depend on the YIG respectively the Co orientation. The amplitude of V_{sc} furthermore depends on the relative alignment of YIG and Co. **(from [1])**

The intriguing discovery in this experiment is the alignment-dependent amplitude of V_{sc} analogous to the spin-polarized charge current transmission in a conventional spin valve. Whereas V_{sr} is not depending on the relative alignment of the layers, the amplitude of V_{sc} is nearly twice as large in the antiparallel alignment state as compared to the parallel state.

The alignment-dependent spin current transport signal amplitude now naturally lends itself to the implementation of a magnon spin valve effect. Comparing the amplitude of V_{sc} for parallel and antiparallel alignment in Fig. 1, we find an amplitude of the magnon spin valve effect of 120%. To check the reliability of the magnon spin valve effect, the magnetization direction of the Co top layer is switched several times in a row and the voltage response towards the applied microwave is recorded. Since in typical application schemes the external field is fixed instead of being swept and thus one voltage level is probed instead of acquiring the whole absorption spectrum, we choose a single fixed field value at which we acquire the signal amplitude. We find a large difference in the signal difference of the total voltage for parallel and antiparallel alignment. We find for instance in Fig. 1 for the sample an absolute voltage difference of 408 nV and a total spin valve effect amplitude of 290%.

In conclusion of this part of the work, we demonstrated the magnon spin valve effect in YIG|CoO|Co multilayers by showing that the spin current transmission signal amplitudes depend on the relative alignment of YIG and Co. The total voltage signal measured includes two contributions whose signs depend individually on the YIG and Co magnetization directions and thus yield different signal amplitudes and signs. This enables one to encode even two bits of information in the magnetic configuration of the spin valve. The presented setup gives a new insight into spin-dependent transport effects in ferromagnetic metals and provides a missing switch component for magnon-based applications thus making the work a key step towards further magnon-based logic gate operation.

Finally in addition to this work, we also studied topological spin structures by a combination of numerical simulations [2] and experimental work [3].
Magnetic skyrmions are promising candidates for future spintronic applications such as skyrmion racetrack memories and logic devices. They exhibit exotic and complex dynamics governed by topology and are less influenced by defects, such as edge roughness, than conventionally used domain walls. In particular, their non-zero topological charge leads to a predicted ‘skyrmion Hall effect’, in which current-driven skyrmions acquire a transverse velocity component analogous to charged particles in the conventional Hall effect. Here, we use nanoscale pump–probe imaging to reveal the real-time dynamics of skyrmions driven by current-induced spin–orbit torques. We find that skyrmions move at a well-defined angle that can exceed 30 degrees with respect to the current flow. In contrast to conventional theoretical expectations, this skyrmion Hall angle increases linearly with velocity. We qualitatively explain our observation based on internal mode excitations in combination with a field-like spin–orbit torque, showing that one must go beyond the usual rigid skyrmion description to understand the dynamics.

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References

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