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Summary

Antiferromagnets (AFMs) have a negative exchange interaction between the nearest neighbouring magnetic moments causing them to align antiparallel, thereby cancelling out the total magnetization. This characteristic minimizes the interaction with probing methods which use magnetization (magnetometry) and spin polarized currents (magnetoresistance). These are the common methods to investigate and employ ferromagnetic (FM) characteristics which allowed for the insurmountable rise of the information technology by reading and writing information on magnetic films. So far, AFMs seem to have few useful properties, as interaction with them is not possible with these common methods. This thesis describes the interaction with AFMs using recently found techniques allowing to investigate spin currents in insulating AFMs.

The employed devices rely on strong spin-orbit coupling in heavy metal thin films of Pt allowing to convert charge current into spin current via the spin Hall effect (SHE) and its inverse (ISHE). Spin currents through the Pt|AFM interface can be created and observed thanks to these effects as a function of the magnetic order: the Néel vector and its excitations. The direction of the Néel vector can be influenced by a large magnetic field. Subsequently, the resistance of the Pt film is modified by the combination of the SHE and the ISHE: the spin Hall magnetoresistance (SMR).

The SMR has previously been employed in various magnetic systems such as ferrimagnets and spin spirals where it is shown to be able to detect the magnetic sublattices individually. Since SMR depends on the square of the magnetization of these sublattices, even when their magnetization cancels out in AFMs, they can be read out. This allowed us to monitor changes in the Néel vector in NiO as a function of a rotating magnetic field. The symmetry and interactions within NiO give rise to numerous domains which are averaged and the influence of a magnetic field on

domains is monitored. Although expected to be only valid close to the Néel temperature and to be highly influenced by temperature dependences in the spin-mixing conductance at the interface and the Pt spin Hall angle and spin diffusion length, the signal size seems to follow the temperature dependence of the magnetic order parameter, the Néel vector.

The rare-earth AFM $DyFeO_3$ represents a next step in complexity after having established these techniques for the most 'simple' rocksalt structured NiO. Its uniaxial AFM Fe^{3+} magnetic sublattices are frustrated by the Dzyaloshinskii-Moriya Interaction (DMI). The interaction of the resulting weak ferromagnetic moment causes the Néel vector to be pushed out-of-plane, making the Néel vector to be very sensitive to small changes in the magnetic field. These observations nicely follow a model which includes in-plane and out-of-plane anisotropy, the Zeeman interaction and DMI. The SMR signal size depends linearly on the applied magnetic field strength and, as a function of temperature, depends on a parameter that can only be described by the influence of the paramagnetic Dy^{3+} orbital moments being aligned by the magnetic field.

The SMR measurements allow to monitor the Morin transition, but also reveal features of magnetic order up to 23 K which have not been reported previously. These features persist below the reported ordering temperatures of Dy^{3+} orbital moments and are believed to be magnetic field-induced.

Next to SMR, NiO and $DyFeO_3$ show the spin Seebeck effect (SSE). The currents through Pt produces Joule heating, causing a current of magnetic excitations, magnons, towards colder parts. A magnon possesses a full spin of $\hbar$ and is a quasiparticle representation of spin waves. AFMs typically have two degenerate modes of magnons with opposite spin. When equally populated, a magnon current will not result in a spin current. A magnetic field can split these modes, causing an imbalance in the populations of these magnon modes and resulting in a spin current.

NiO possesses multiple magnon modes with different energy shifts as a function of the applied magnetic field. These changes cause the SSE signal to depend on the magnetic field as confirmed by modelling. The studied magnons are injected due to Joule heating of a narrow Pt strip after which they propagate through the AFM insulator and can be detected at a second Pt strip. In FMs, magnons decay following a diffusion-relaxation model, showing an exponential decay in the magnon chemical potential and the SSE signal. In NiO, however, there are large variations between devices while the signal size and the spread in the data points increase when the magnon chemical potential is influenced by local accumulations of magnons. This can occur at crystallographic impurities or domain walls.

To further investigate the effect of impurities as well as exchange bias on NiO, thin films of NiO were grown on the ferrimagnetic YIG. In a non-local geometry, these bilayers were investigated on their capabilities to transmit different kinds of spin currents. The NiO films show to be transmissive to the spin transfer torque applied during an SMR measurement. At room temperature, the spin current reaches the YIG after which the information about the YIG's magnetic order is transported back to the Pt. At low temperatures, this spin current does not reach the Pt again and the signal is dominated by the magnetic order of NiO. Magnons, injected electrically by the SHE or by heating via the SSE show a similar temperature dependence; the spin current measured at the detector is damped out at low temperatures. Especially, the electrically injected magnons transported to the detector are damped out since they have to pass the NiO twice. On the other hand, a recurring SSE generated spin current in the NiO is observed at low temperatures, comparable to the SSE signals observed in bulk NiO. Even though the films are opaque for electrically injected magnons, they seem transmissive to the heat-generated magnons.

The effect of magnetic ordering is revealed by magnetic field dependent measurements. All SMR measurements show a quadratic contribution by increasing the magnetic field. At room temperature, the NiO thin films show an increased transmissivity while the thicker films show a larger Néel order. The thinnest film at 5 K, however, shows a sign change caused by a quadratic increase of transmissivity to dominate over the interaction with the larger AFM order. Only the recurring SSE signals at low temperatures show an increase in signal strength similar to the SSE signals observed in bulk NiO.