Theoretical Challenges in Spintronic Materials

In the past two years we studied the theory of spintronics in the context of materials relevant for the experimental research at the IMR and elsewhere in the form of an ICC-IMR Integrated Project. The ICC-IMR helped to start up the new Theory of Condensed Matter Group to be integrated into the IMR environment and to enhance the international impact of IMR spintronics research.

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In this project we addressed many issues of spintronics. For the present Activity Report we would like to present selected topics of our research into magnetic insulators, spin-pumping and spin Hall effects, as well as results obtained in the fields of spin caloritronics and and spin optics.

Magnetic insulators

The invention of thermal and electric actuation of the magnetic insulator Yttrium-Iron-Garnet by means of the direct and inverse spin Hall effect has attracted a lot of international attention. Fig. 1 is a sketch of the basic physical scattering process that couples the magnetization in insulators with metal electronics by spin momentum transfer that does not require charge transfer and is therefore operative as well for magnetic insulators.

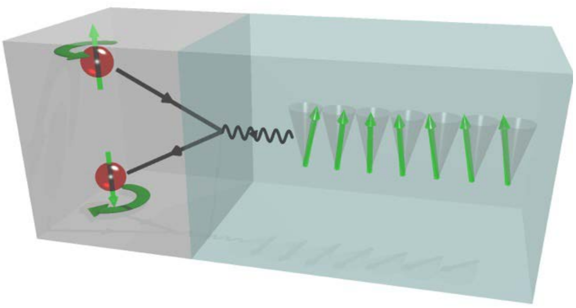

Fig. 1: The “bosonization of spintronics” rests on the magnon creation in magnetic insulators (right) by spin-polarized electron hole pairs or spinons (left).

In collaboration with the TU Delft and Fudan University with support by the ICC-IMR we studied various properties of YIG and its heterostructures. For example, we computed the critical currents for magnetic excitations (KINKEN Research Highlights 2012) and explained the recently discovered spin Hall magnetoresistance (SMR) that is described in the accompanying ICC-IMR research highlight.

Spin caloritronics

Several recent experiments at the IMR and elsewhere discovered interesting spin effects in magnetic nanostructures, contributing to the field of spin caloritronics, the science and technology of controlling charge, spin, and heat currents [1]. Theory has made progress by the qualitative elucidation of the basic mechanism of the spin Seebeck effect [1]. In the present project we continued to be active in this field, which led to results such as the domain wall heat conductance in magnetic insulators [2]. We found that the heat conductance is modulated by the magnetization texture when the domain wall width d becomes of the order of magnitude of the lattice constant $\boldsymbol{a}$ as illustrated in Fig. 2.

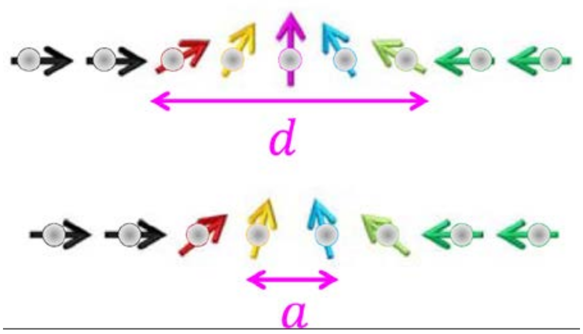

Fig. 2: Two head-to-head magnetic domain wall configurations with different energies illustrating the concept of atomic pinning for narrow domain walls when the domain wall width d becomes of the order of the lattice constant $\boldsymbol{a}$ [2]

AC spin Hall effect

The spin current pumped by a precessing ferromagnet into an adjacent normal metal has a constant polarization component parallel to the precession axis and a rotating one normal to the magnetization. The former is now routinely detected as a DC voltage induced by the inverse spin Hall effect (ISHE).

In collaboration with the TU Delft we found AC ISHE voltages much larger than the DC signals for various material combinations and discuss optimal conditions to observe the effect [3]. The backflow of spin is shown to be essential to distill parameters from measured ISHE voltages for both DC and AC configurations. We believe that this backflow should have ramifications for other effect in ferrogmagnet-normal metal bilayers, such as the spin Seebeck effect.

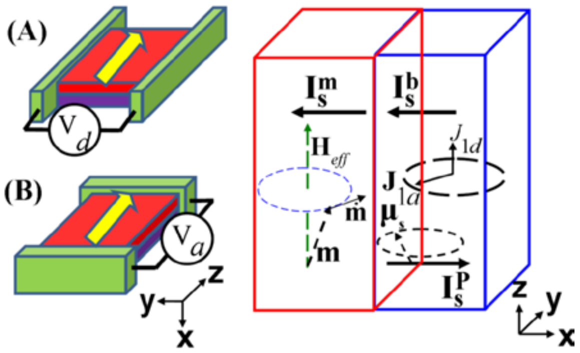

Fig. 3: Schematic spin battery operated by FMR for the measurement configurations (A) and (B). The AC(DC) voltage drops V_a (V_d) along the z(y) direction. In the right panel the magnetization **m** (time derivative precesses around the effective field H_{eff} in the left layer, generating DC/ AC spin currents and a spin accumulation in the normal metal (right side) [3].

Spin optics

Present magnetic storage technology is slow; switching of a bit takes of the order of a nanosecond, and switching by currents by use of the spin transfer torque does not appear to improve the switching speed much. A possible way out is the switching by light pulses, which can be very fast. Magnetization reversal by fs laser pulses has been demonstrated, but the basic physics has not yet been well understood. In collaboration with the NTNU Trondheim, Norway, we developed a theory for the light-induced magnetic fields in magnetic semiconductors [4], which are interpreted as a spin-dependent AC Stark effect. As result, we predict that at experimentally achievable light intensities effective magnetic fields of the order of 10's of tesla's can be realized.

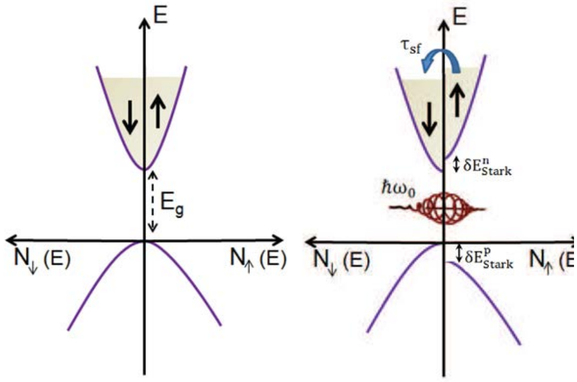

Fig. 4: Illustration of the changes in the majority and minority population due to the Stark shift in the presence of non-resonant and intense circularly polarized laser field that acts as an effective magnetic field to create a spin accumulation or exert torques on a magnetization [4].

References

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