Lecture at the European School of Magnetism 2015

Spin electronics and caloritronics of magnetic insulators (1.5 h)

Gerrit Bauer, Institute for Materials Research, Tohoku University, Japan

Spin caloritronics is the science and technology striving to understand and control not only spin and charge, but also heat currents in small structures and devices [1]. Spin caloritronic effects can be roughly classified into two groups. In ferromagnetic metals and its heterostructures the two-current series resistor mode works well to describe the giant magnetoresistance and related phenomena. Thermoelectrics can be formulated in a two current model as well [2], leading to phenomena such as the spin-dependent Seebeck and Peltier effects. The elementary excitations of the order parameter of a ferromagnet are spin waves or magnons that may carry spin and heat currents as well. The thermal actuation of spin waves by metallic contacts and the thermal pumping of spin current into the contacts lead to the phenomena of the spin Seebeck and spin Peltier effects that are relatively easy to observe and analyze in magnetic insulators [3] such as the ferrimagnet yttrium iron garnets (YIG). These materials have been studied intensively for half a century and can be grown with exceptional magnetic quality.

This lecture addresses the electric and thermal properties of magnetic insulators with and without metal contacts. We will discuss the theory of electric and thermal actuation of the magnetic order parameter in these structures at the interfaces and the bulk of the magnet. Topics to be discussed are:

(1) Magnetic insulators
- (a) YIG crystal structure and properties
- (b) Spin waves in YIG

(2) Bilayers of magnetic insulators and normal metals
- (a) Spin torque and spin pumping
- (b) Spin Seebeck effect
- (c) Spin Hall magnetoresistance

(3) Onsager analysis

(4) Spin Seebeck effect in rare-earth doped YIG

Bibliography

[1] G. E. W. Bauer, E. Saitoh and B. J. van Wees, Spin caloritronicsNat. Mat. **11**, 391 (2012).

[2] M. Johnson and R. H. Silsbee, Thermodynamic analysis of interfacial transport and of the thermomagnetoelectric system. Phys. Rev. B **35**, 4959 (1987).
[3] G.F. Dionne (2009), *Magnetic Oxides*. Springer.