# Spin Electronics and Spin Caloritronics

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One of the fundamental bottlenecks in developing spin electronics is to find materials and mechanisms that allow electrical currents to convert efficiently to spin currents. While the spin Hall effect has been demonstrated experimentally, devices based on semiconductors show very small effects as expected [1], since the effect depends on relativistic spin-orbit coupling. Recently a gigantic spin Hall effect at room temperature was discovered in a device fabricated at Tohoku University with injectors made of iron platinum alloys and a gold cross bar [2]. A qualitative theory was advanced explaining this surprising result in terms of resonant skew scattering by individual Fe atoms in the Au host [3]. The scattering by spin-orbit coupling is enhanced by Kondo-type many body interactions even at room temperatures, since the crystal field splitting leads to an orbital Kondo effect with a high temperature scale in addition to the standard Kondo temperature below 1K. Note that the orbital Kondo effect comes from the strongly coupled crystal field levels. The original predictions of Guo et al. relied on band structure calculations which must be supplemented by techniques that partly include many-body fluctuations of strongly correlated electrons [3]. In own recent numerical studies, Quantum Monte Carlo methods have been applied, which supported this interpretation and gave quantitative predictions down to room temperature [4,5]. Nevertheless important questions remain, particularly as concerns consistency with measurements of transport [6] and orbital magnetism [7] performed at low temperatures on systems close to the model proposed: i. e. dilute alloys of Fe in gold.

A second theme of the project aims at spin motive force (smf) in magnetic nanostructures. Faraday's law of induction is a basic principle of physics which explains an electromotive force that drives electrical currents in generators and transformers. Recently, it has been revealed that, in magnetic materials, there is a correction to this law, which can be restated in terms of the so-called “Berry phase” [8-9]. The Berry phase is a geometric phase, which appears ubiquitously in the context of condensed matter physics, optics, quantum computation, etc. In addition, “spin Berry phase” for an electron is $-\Omega/2$, where $\Omega$ is the solid angle subtended by the path of the order parameter $\mathbf{n}$ in spin space. The simple example is a ferromagnetic wire which lies along the z direction and which contains a single domain wall of a transition region connecting two magnetic domains. For a DC magnetic field **B** along the z axis, the wall starts to precess so that it develops a time dependent solid angle, $d\Omega/dt = \pm 4\mu B/\hbar$, for conduction electrons traversing the wire. The + (-) sign corresponds to spin-up (-down) of the electrons. This generates a "spin-motive force" $\varepsilon_{s\pm} = \pm 2\mu B/e$, and hence, an electromotive force $\varepsilon = 2p\mu B/e$, where p is a spin polarization of the ferromagnet. The magnitude is evaluated for typical itinerant ferromagnets, e.g., $Ni_{81}Fe_{19}$, $\varepsilon \sim 100$ [μV/T]. It is therefore possible to read the state of a magnetic memory device via the emf. We have examined the possibility to amplify currents in pulse circuits, opening up all magnetic logic circuits.

**References**


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