Modeling "circuits" with spins and magnets

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Recent advances have clearly established that magnets can be used to inject spin currents which in turn can be used to switch magnets, thus integrating the two distinct fields of spintronics and magnetics into a single field. This talk will summarize our progress in the last few years on developing a general modeling framework for the analysis of "spin-magnet circuits" and benchmarking against available experimental data.

This model combines the standard theory for magnet dynamics with the transport theory for spins (Fig.1). Applications of the model to practical devices at this time seems limited to magnetic tunnel junctions (MTJ's) for which the spin transport can be described using the non-equilibrium Green's function (NEGF) method. Such devices, which are being considered for memory applications, usually involve at most one free magnetic layer whose dynamics is described by the Landau-Lifshitz-Gilbert (LLG) equation.

It is possible to envision spin-based logic devices in the future which would include device components for the injection, detection and transmission of spin/charge currents that can communicate information between multiple free magnets which act like "spin capacitors" storing digital information.

To explore the feasibility of such devices we have developed a model which (1) includes multiple LLG equations, one for each free magnet and (2) uses a novel formulation that casts spin transport in a form similar to ordinary circuits, but with voltages and currents having four components each (one for charge, three for spin) that are related by 4x4 conductance matrices.

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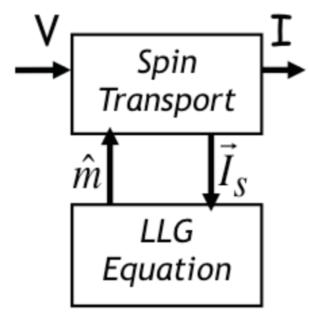

Figure 1: Devices with one free magnetic layer can be described by a model that couples (a) a description of spin transport that calculates the charge and spin currents I, $\vec{I}_s$ for a given voltage V and magnetization $\hat{m}$,with (b) a description of the free layer magnetization $\hat{m}$ for a given spin current $\vec{I}_s$ using the LLG equation.

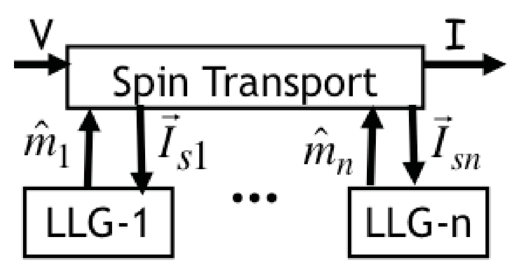

Figure 2: To model extended devices with multiple free magnetic layers we have developed a model with an LLG equation for each free layer and a "spin circuit" approach to transport involving 4-component voltages and currents related by 4x4 conductance matrices.

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