Electronic transport and magnetization dynamics in realistic devices: a multiscale approach

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The mutual interaction between spin transport and magnetization dynamics in hybrid nano-devices is at the origin of physical effects, such as Spin Transfer (ST) [1] and Giant Magneto Resistance [2], which act at very different length scales, and depend both on the microscopic characteristics of the material and on the geometry of the device. These effects opened a potential for various applications, such as magnetic memories, reprogrammable logic, and Spin Torque Nano Oscillators (STNO) [3]. The physics of those devices cannot be captured by simple (analytically tractable) models, and numerical simulations that can be easily adapted to different geometries, length scales and materials are of primary importance to describe realistic systems.

We report on a theoretical model, based on Continuous Random Matrix Theory (CRMT) [4] and Non Equilibrium Green Functions [5], that describes on an equal footing transport and magnetic degrees of freedom in realistic devices. The model has been implemented in a simulation code [4,6] that allows one to compute local (spin torque, spin accumulation and spin/charge current) and macroscopic (resistance) transport properties of spin valves. Our approach offers a systematic way to perform multiscale simulations [7] in heterogeneus systems with arbitrary geometry, connected to an arbitrary number of electron reservoirs. Bulk and interface properties of very different materials (magnetic and non-magnetic metals, insulators, semiconductors, superconductors) are properly captured by our model, which can be parametrized using both experimentally accessible parameters and ab initio calculations. As an application of our method, we have coupled CRMT to a micromagnetic simulation code, in order to model a spectroscopic experiment [8], based on a mechanical detection of the ferromagnetic resonance, and performed on a STNO. Our simulations predict correctly the selection rules for spin wave (SW) modes excited by ST, and give a description of the complex dynamics of the magnetization in qualitative agreement with experiments [9]. Our multiscale approach can be coupled to other micromagnetic or spin dynamics codes, and offer a systematic way to compute current driven dynamics in different systems.

[1] J. Slonczewski, J. Magn. Mater. 159 (1996), L1.
[2] T. Valet and A. Fert, Phys. Rev. B 48 (1993), 7099.
[3] A. Slavin, V. Tiberkevich, IEEE Transactions on Magn. 45, 4 (2009),

1825.
[4] V. Rychkov et al., Phys. Rev. Lett. 103 (2009), 066602.
[5] K. Kazymyrenko and X. Waintal, Phys. Rev. B 77 (2009), 115119
[6] I. Rychckova et al., arXiv: 1010.2627v1 (2010).
[7] S. Borlenghi et al., Phys. Rev. B 84 (2011), 035412.
[8] V. V. Naletov et al., arXiv: 1107.5699 (2011).
[9] S. Borlenghi et al., "Identification of spin wave modes excited by spin torque in a nanopillar", in preparation.