Spin pumping in magnetic tunnel junctions and topological insulators: Theory and experiment

Branislav K. Nikolic[1, 2], Farzad Mahfouzi[1], John Q. Xiao[1], and Naoto Nagaosa[2, 3]

[1] *University od Delaware, Department of Physics and Astronomy, 217 Sharp Lab, Newark 19716, USA*

[2] *Cross Correlated Materials Research Group (CMRG), ASI, RIKEN, Wako 351-0198, Japan*

[3] *Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan*

The pursuit of the "second-generation" spintronics has been focused on harnessing coherent spin states. The salient examples of phenomena involving both coherent spins and their time evolution is the spin-transfer torque (STT) and its Onsager reciprocal effect, termed spin pumping because it occurs in setups without applied bias voltage, where microwave driven precessing magnetization of a single ferromagnetic (F) layer emits pure spin current into adjacent normal metal (N) layers. While pumped spin current has been detected by converting it into $\sim$ 10 nV voltage signal in N1|F|N2 junctions, a puzzling and much larger signal $\sim$ 1 μV was measured in our recent experiments [1] on F|I|N tunnel junctions with AlO_x insulating barrier I. This observation is unexpected in both standard scattering theory and nonequilibrium Green function (NEGF) in the rotating frame [2] approaches to pumping which predict no signal at adiabatic level $\sim \omega$. However, neither of these two approaches is capable of taking into account strong spin-orbit coupling (SOC) directly at the F|N pumping interface, such as the Rashba one demonstrated to exist in recent experiments on STT in F|I|N junctions. Unlike the recent theoretical efforts on STT in the presence of SOCs, very little is known about such effects on spin pumping. Here we discuss a novel solution [3] to time-dependent NEGFs, which describes pumping in the presence of SOC exactly at the level of one microwave photon absorption or emission processes, to explain $\sim \omega$ voltage signal observed experimentally [1]. We also discuss pumping into 2D topological insulators (TI) whose helical edge states lead to quantized pumped spin current even at very small input microwave power thereby generating giant spin battery effect [4]. Finally, the unique voltage signal of spin pumping in vertical F|TI junctions can be employed to detect quantum Hall liquid on the surface of three-dimensional TIs in proximity to F.

[1] T. Moriyama, R. Cao, X. Fan, G. Xuan, B. K. Nikolic, Y. Tserkovnyak, J. Kolodzey, and J. Q. Xiao, Phys. Rev. Lett. 100, 067602 (2008).

[2] S.-H. Chen, C.-R. Chang, J. Q. Xiao, and B. K. Nikolic, Phys. Rev. B 79, 054424 (2009).

[3] F. Mahfouzi, B. K. Nikolic, and N. Nagaosa, in preparation.

[4] F. Mahfouzi, B. K. Nikolic, S.-H. Chen, and C.-R. Chang, Phys. Rev. B 82, 195440 (2010).