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A Unified Quantum Theory of Spin Transfer Torque and Electron Transport in Magnetic Nanostructures[1]

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Dynamical control of nanoscale magnetization by spin-polarized current has attracted intensive studies due to its vast potential applications in spintronics. The magnetization dynamics driven by spin transfer torque is usually described by the semiclassical theory, where the quantum nature of the magnet is neglected. Here, we present a unified theory which describes the magnetization and the spin-polarized electrons at the full quantum level. The quantum state of the magnetization is given by the coherent state in angular momentum space, and is driven by the continuous scatterings with the electrons in the stochastic nature. Based on this picture, the Monte Carlo simulation is applied to get the mean trajectory and fluctuations of the magnetization, and also the electric current and the current shot noise. We also analyze the different sources which contribute to the magnetization noise and current noise, and show that the quantum noise due to the scattering can be comparable to the thermal noise at low temperature. An analytic theory is also formulated in terms of the density matrix technique. We obtain the master equation of the density matrix of the magnet driven by spin transfer torque, and find that it becomes a Fock-Planck equation in the coherent representation. Solutions from this approach is highly consistent with the results from the Monte Carlo method. We forsee that our theory will play an important role when the quantum nature of the nanomaget emerges in the spintronics devices. For references, see [1] Yong Wang and L.J. Sham, Quantum Dynamics of a Nanomagnet driven by Spin-Polarized Current, arxiv : 1106.2359. [2] Yong Wang and L.J. Sham, A Quantum Theory of Spin Transfer Torque, to be submitted.

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