Spin-transfer torque effects in thermally assisted magnetization reversal

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Due to the spin-transfer torque (STT) effect [1], the magnetization of a nanoscale ferromagnet may be altered by spin-polarized currents. This phenomenon occurs because an electric current with spin polarization in ferromagnet has an associated flow of angular momentum thereby exerting a macroscopic spin torque. Thermal fluctuations of nanomagnets driven by spin-polarized currents are treated via the Landau-Lifshitz-Gilbert equation for the magnetization $\mathbf{M}$ generalized to include both the random thermal noise field $\mathbf{h}(t)$ and the Slonczewski spin-transfer torque (STT) term $\dot{\mathbf{u}}_{\mathrm{ST}}$ [1], viz.,

$$\dot{\mathbf{u}} = -\gamma \mathbf{u} \times \left(\mathbf{H}_{\mathrm{eff}} + \dot{\mathbf{u}}_{\mathrm{ST}} + \mathbf{h}\right) + \alpha \mathbf{u} \times \dot{\mathbf{u}}, \qquad (1)$$

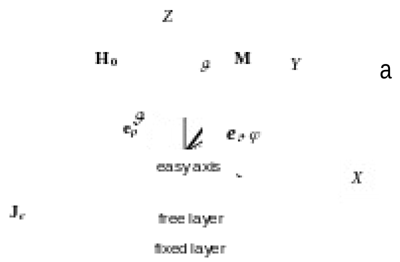

FIG. 1. Geometry of the problem: A STT device consists two ferromagnetic strata labelled the *free* and *fixed* lay respectively, and a normal conducting spacer all sandwiched a pillar between two ohmic contacts. The fixed layer ha fixed magnetization along the direction $\mathbf{e}_p$. $\mathbf{J}_e$ is the sp polarized current density, $\mathbf{M}$ is the magnetization of the f layer, and $\mathbf{H}_0$ is the dc magnetic field.

where $\mathbf{u} = \mathbf{M}/|\mathbf{M}|$ is a unit vector directed along $\mathbf{M}$, γ is the gyromagnetic-type constant, $\mathbf{H}_{\mathrm{eff}}$ is the effective magnetic field comprising the anisotropy and external dc fields and α is the dimensionless damping parameter. The magnetization reversal time of such a nanomagnet is then evaluated for wide ranges of damping by using a method which generalizes the solution of the so-called Kramers turnover problem for mechanical Brownian particles thereby bridging the very low damping and intermediate damping Kramers escape rates, to the analogous magnetic turnover problem [2]. The reversal time is then evaluated for a nanomagnet with the free energy density given in the standard form of superimposed easy-plane and in-plane easy-axis anisotropies with the dc bias field along the easy axis. It is shown [3] that the damping dependence of the magnetization reversal time is very marked in the underdamped regime $\alpha < 1$, a fact which may be very significant in interpreting many STT experiments. Two important merits of the escape rate equations for the reversal time are that (i) they are relatively simple (expressed via elementary functions) and (ii) that they can be used in those parameter ranges, where numerical methods of solving Eq. (1) may be no longer applicable. The approach developed allows us to predict [3] new spin-torque effects in the thermally assisted magnetization reversal which may comprise several orders of magnitude.

[1] J. C. Slonczewski, J. Magn. Magn. Mater. **159**, L1 (1996).

[2] W.T. Coffey and Y.P. Kalmykov, J. Appl. Phys. (Appl. Phys. Reviews), **112**, 121301 (2012).

[3] Y.P. Kalmykov, D. Byrne, W.J. Dowling, W.T. Coffey, S.V. Titov, and J.E. Wegrowe, IEEE Trans. Magn., **53**, 1400308 (2017).