Spin-torque switching in perpendicular media: temperature effects on the phase diagram

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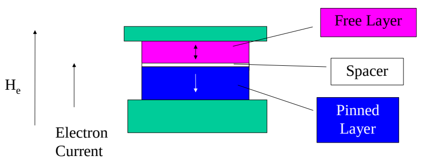
Summary

We give the phase diagram for perpendicular spin torque switching at T=0 and show how the phase boundaries shift at finite temperature.

Spin-torque switching: Background

Spin-torque switching is a promising candidate for future information storage. The information is stored in the magnetization of a "free layer" (blue in figure below) which can be switched by passing current into it from a "pinned layer":



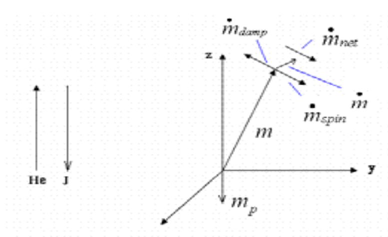
This geometry has been studied theoretically and experimentally [S. Mangin, D. Ravelosona, J. A. Katine, M. J. Carey, B. D. Terris, and Eric E. Fullerton, Nature Materials **5**, 210 (2006), …] – in this paper we show how the phase diagram can be understood in terms of the effective-energy landscape.

Landau-Lifshitz equation

We use the Landau-Lifshitz equation in the form

$$\frac{d\mathbf{M}}{dt} = -\gamma\mathbf{M}\times\mathbf{H} - \frac{\gamma\alpha}{M_s}\mathbf{M}\times(\mathbf{M}\times\mathbf{H}) - \frac{\gamma J}{M_s(1+B\cos\theta)}\mathbf{M}\times(\mathbf{M}\times\mathbf{m}_p)$$

The last (spin torque) term involves a quantity J which is proportional to current and sp polarization, with units of magnetic field. We use the Slonczewski form of the spin torque term whose angle dependence involves a dimensionless constant B. Here m_p is the pinned magnetization direction (assumed normal to the film plane here) and q is the angle between this and M. The diagram at right shows the contributions to the torque in the LL equation due to precession, damping, and spin torque. Damping narrows the precession cone, spin torque enlarges it.



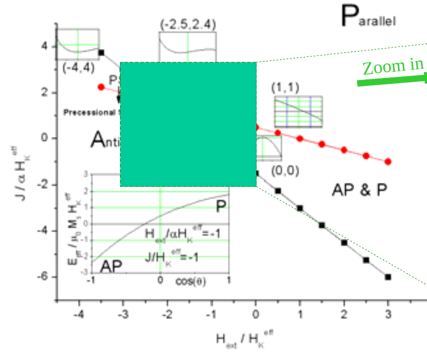
To study stability at finite temperature, we use the steady state solution to the Fokker-Planck equation [D. M. Apalkov and P. B. Visscher, Physical Review B 72, 180405R (2005); Z. Li, J. He, and S. Zhang, Phys. Rev. B 72, 212411 (2005)],

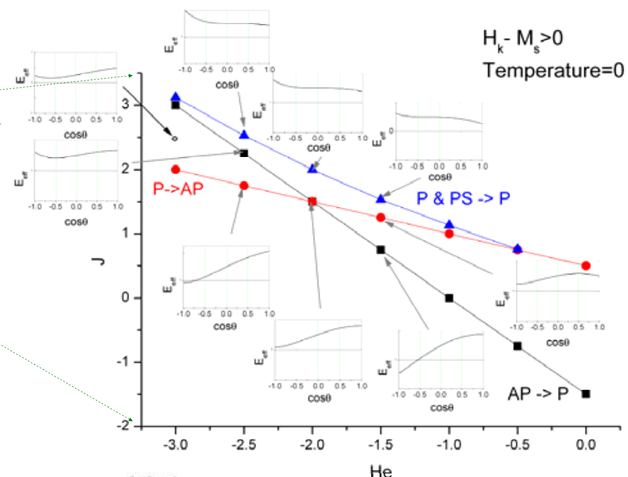
$\rho(E) = \exp(-E_{eff}/kT)$, where the computation of the effective energy $E_{eff}(E)$ is complicated in the parallel case, but in the perpendicular case can be thought of as the integral of the torque with respect to angle:

$$E_{eff} = -\frac{\mu_0 M_s V}{\alpha\gamma}\int \dot m_{net}\, d\theta = -\frac{\mu_0 M_s V}{\alpha\gamma}\int \gamma\sin\theta\{-[(H_k - M_s)\cos\theta + H_e]\alpha + \frac{J}{1+B\cos\theta}\}d\theta$$

$$= \mu_0 M_s V[\frac{1}{2}(H_k - M_s)\sin^2\theta - H_e\cos\theta + \frac{J}{\alpha B}\ln(1+B\cos\theta)]$$

From this formula, we can work out the phase diagram (shown at the upper right) – relative minima are stable states, and phase boundaries occur when a minimum disappears. At each point of the phase diagram, we can graph E_{eff} as a function of angle θ, or (more naturally) cos(θ) -- such insets are shown at several points, labeled by current J and external field H_e.





T>0 phase diagrams

When T>0, the system switches before the energy barrier vanishes