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**Current Induced Switching by Spin Torque Including the Effects of Temperature**[1]

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Recently it has been shown[1] that the magnetization **M** of submicron patterned thin-film ferromagnetic elements can be switched by passing a current from another (pinned) ferromagnetic layer. This phenomenon could lead to a new type of high-density non-volatile MRAM (magnetic random access memory). The incoming electrons deposit their spin angular momentum in the ferromagnet, where it adds to the local vector magnetization. Quantitatively, one adds a "spin torque" term to the Landau-Lifshitz equation for $d\mathbf{M}/\mathbf{dt}$, proportional to the component of the pinned magnetization perpendicular to **M**. The familiar Arrhenius-Neel reaction rate formula [$\propto \exp(-E_b/kT)$, where $E_b$ is a potential energy barrier] cannot be used for this problem, because the spin-torque is not conservative so a potential energy cannot be defined. We have gone back to the fundamental Fokker-Planck equation from which the Arrhenius-Neel result was derived and reformulated it including the spin torque. We obtain a simple differential equation for the energy distribution, which gives the expected $\exp(-E/kT)$ if the current vanishes. In the limit of small oscillations about an easy axis, the energy distribution can be approximated by a Boltzmann distribution with an elevated effective temperature, allowing the use of an Arrhenius-Neel-like rate formula. This picture gives an adequate accounting[2] of room-temperature telegraph noise rates, for example. However, at low temperature the distribution resulting from our theory is qualitatively unlike a Boltzmann distribution, and describes the statistics of recently-observed large-amplitude precessional states[3], which have possible applications to tunable gigahertz oscillators. In addition to these steady-state applications, the new Fokker-Planck equation can model the effects of nanosecond current pulses in high-speed MRAM. [1] F. J. Albert et al, Appl. Phys. Lett. **77**, 3809 (2000). [2] D. M. Apalkov and P. B. Visscher, cond-mat preprint 0405305. [3] S. I. Kiselev, Nature **425**, 380 (2003).

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