Energy barrier of composite free layer for magnetic tunnel junction

Soo-Man Seo*, and Kyung-Jin Lee
Department of materials science and engineering, Korea University
*kj_lee@korea.ac.kr

The ferromagnetic element with the thin-film geometry has attracted much attention due to its potential application for spin-valve read sensors of the hard disk drive and magnetic random access memories (MRAMs). From the technological points of view, the thermal agitation of the magnetization becomes significantly important as the volume of the magnetic cell decreases. For example, the so-called magnoise is a manifestation of the thermally excited ferromagnetic resonance in the spin-valve read sensor [1,2], and the scale-down of STT-MRAM utilizing spin-transfer torque (STT) [3,4] is hindered by a trade-off relation between the thermal activation energy and the critical current density for the magnetization switching.

Recently, a composite free layer consisting of the soft (hard) layer with the in-plane (perpendicular) anisotropy was proposed for a sufficient thermal stability for which the magnetization cannot spontaneously change its direction during the lifetime of the device and a reducing switching current (or field) [5]. According to Néel-Brown model [6,7], for a single homogeneous ferromagnetic layer the thermal fluctuation occurs at a rate of $\tau^{-1}=\tau_0^{-1}\exp(K_{eff}V/k_BT)$, where K_{eff} is the effective magnetic anisotropy, V is the volume, k_B is the Boltzmann constant, and T is the temperature in Kelvin so that the thermal stability factor is simply given by $K_{eff}V/k_BT$. Such a statistical behavior of superparamagnetic particle was well demonstrated experimentally [8]. In contrast, for a composite layer the thermal stability is not given by suchasimple expression due to the interaction between two layers (ortwoparticles).

In this work, we estimated the thermal stability of the composite free layer according to the saturation magnetization of the soft free layer. Since for a thermally activated switching the magnetic energy should pass through saddle point from local minimum to global minimum, the energy barrier theoretically from the energy surface with variable angle of the magnetization. This theoretical prediction was verified by means of a numerical model based on stochastic Landau-Lifshitz-Gilbert (LLG) equation.

Figure 1 (a) shows the schematics of the system where θ and $\varphi$are the polar angle and the azimuth alangle of the magnetization vector. We considered the soft layer $\boldsymbol{m_1}$ with M_S=0~1000emu/cm^3, K_u=0, α=0.01, and t=3 nm and the hard layer $\boldsymbol{m_2}$ with M_S=1000emu/cm^3, $\boldsymbol{K_u}$=4.23 × 106erg/cm^{-3}, α=0.01, and t=3 nm where $K_{eff}V/k_BT$ of the hard layer is about 8 because of excessive computation time, and two layers were separated by the spacer with t=1nm. For the thermally activated switching, the temperature was assumed to be 300 K. Probability of switching P_{sw} was estimated by counting the number of successful switching out of 500 switching events.

Figure 1(a) shows the probability of not switching with time for several cases of the saturation magnetization of the soft layer (M_S^{soft}). It is definitely shown the linear relationship between ln($1-P_{SW}$) and the time, which imply that the switching probability is well described by the Arrhenius-Néel relation. From the slope of them, one can estimate the thermal stability $K_{eff}V/k_BT$ depending on the attempt frequency. Figure 1(b) shows the thermal stability as a function of M_S^{soft}, where the solid line corresponds to the estimated value from the energy surface, and the symbols indicate the values estimated from the macro spin calculation (Fig. 1(a)) for a several attempt frequencies, since the attempt frequency is not constant but depends on many parameters such as the damping constant, the magnetic properties, and the shape of the system [9]. In both approaches, the thermal stability slightly increases up to M_S^{soft}=100 (150) emu/cm^3 for theoretical prediction (macrospinmodel), then decrease with increasing M_S^{soft}. From the Eq. (2) in Ref. [9], we obtained the attempt frequency is about 0.197 for M_S^{soft}=0. However, for $M_S^{soft}\neq 0$ the theory is not yet developed.

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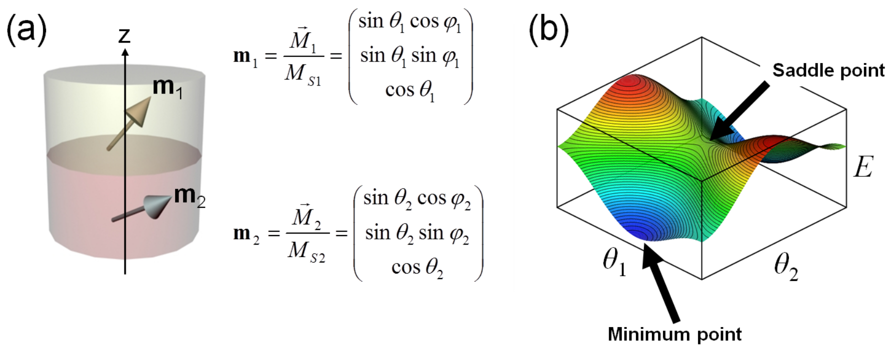

Fig. 1. (a) Schematics of the system. (b) Magnetic energy surface.

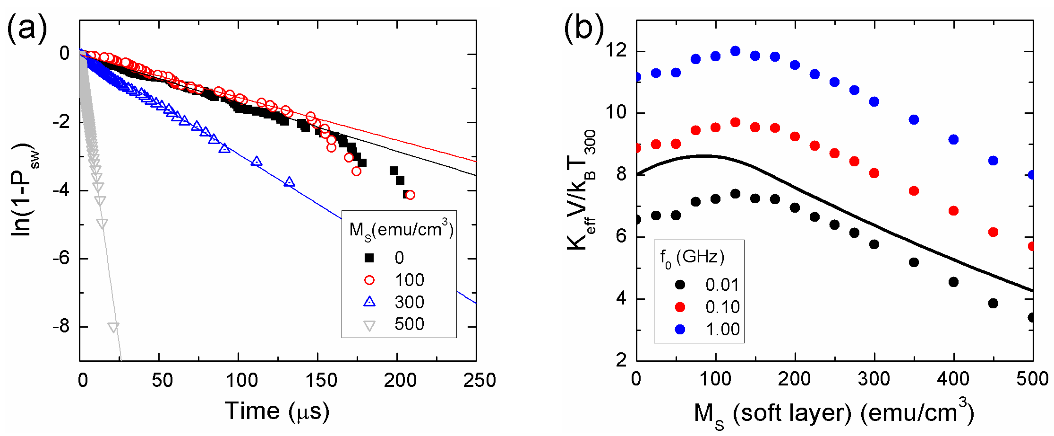

Fig. 2. (a) Probability of not switching with time. (b) Thermal stability as a function of the saturation magnetization of the soft layer.