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Micromagnetics of thermally activated switching in nonuniformly magnetized nanodots

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Abstract

Patterned magnetic elements are being proposed as media for the future ultrahigh density storage systems. The equilibrium states of different patterned magnetic dots at zero temperature have been studied in numerous micromagnetic works while in the last year some studies have begun to include the effect of temperature in the computations. In this research a stochastic dynamic micromagnetic study is carried out for rectangular magnetic dots with size 10 by 3.1 times the exchange length, patterned in a film with a thickness of 5 times the exchange length. Two kinds of nonuniform magnetized nanodots are studied in detail: those in which the state prior to the switching follows the shape of a 'C' and those following an 'S'. In both cases a field near to the zero-temperature switching field is applied and then the thermally activated switching is observed. The dependence of the switching time on temperature is analyzed. It is observed how for the 'C' configuration an Arrhenius-like behavior is obtained in a large temperature window while this is not the case for the 'S' configuration. The micromagnetic structure of the switching thermally activated modes leading to these behaviors is also studied. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Micromagnetism; Magnetic recording media; Switching fields; Temperature effects

Patterned magnetic nanostructures are being deeply studied both experimentally and theoretically in order to delimitate their real possibilities as the future materials for applications as magnetic recording or magnetic sensors [1–4]. Most of the micromagnetic dynamic simulations found in the literature are performed at zero temperature but there are also some works in which the Langevin dynamics of the micromagnetic states is analyzed at non-zero temperature [5–7].

In this paper a stochastic dynamic micromagnetic study is carried out for rectangular magnetic dots with size 10 by 3.1 times the exchange length ($l_{ex} = (A/2\pi M_s)^{1/2}$), patterned in a film with a thickness of $5\,l_{ex}$. These sizes are in the range analyzed in Ref. [1], where thermal effects have been claimed. A stochastic zero-mean gaussian field is introduced in the Landau Lifschitz Gilbert equation and the corresponding Langevin equation is solved numerically. Regular 2D square meshes of 32×10 and 64×20 cells are used, in each cell the magnetization is allowed to rotate in 3D. For every temperature, more than 200 simulations are performed to obtain the statistics; in some cases 2000 realizations were calculated to test convergence. More details can be found in [4,7].

Two types of initial zero-temperature configurations ('C' and 'S'), as shown in Fig. 1, are computed. These states are obtained just before the magnetic switching along the 'x' direction (See Fig. 1). In order to attain this kind of states a uniaxial magnetocrystalline anisotropy along the 'y' direction has been considered ($l_{ex}/\delta = 0.5, \delta = (A/K)^{1/2}$ K being the anisotropy constant). The 'C' or 'S' magnetized dot is then submitted to an external field. $H_{ext} = 0.98\ H_{switching,T=0}$, (i.e. slightly less than the zero-temperature switching field) and the effect of the non-zero temperature is analyzed. Thermally

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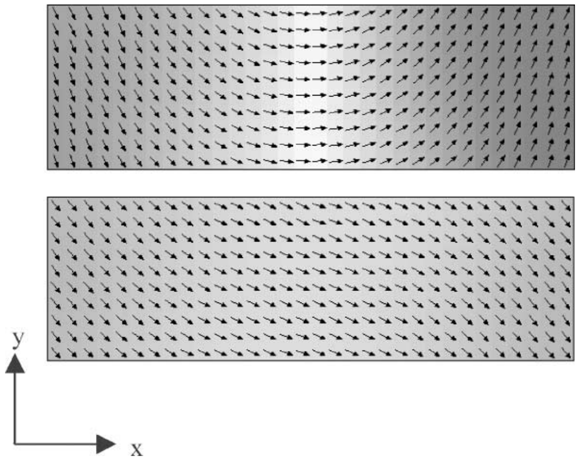

Fig. 1. Arrow and density plot of the two kinds of initial states considered in the stochastic simulation. Top: 'C' configuration. Bottom: 'S' configuration.

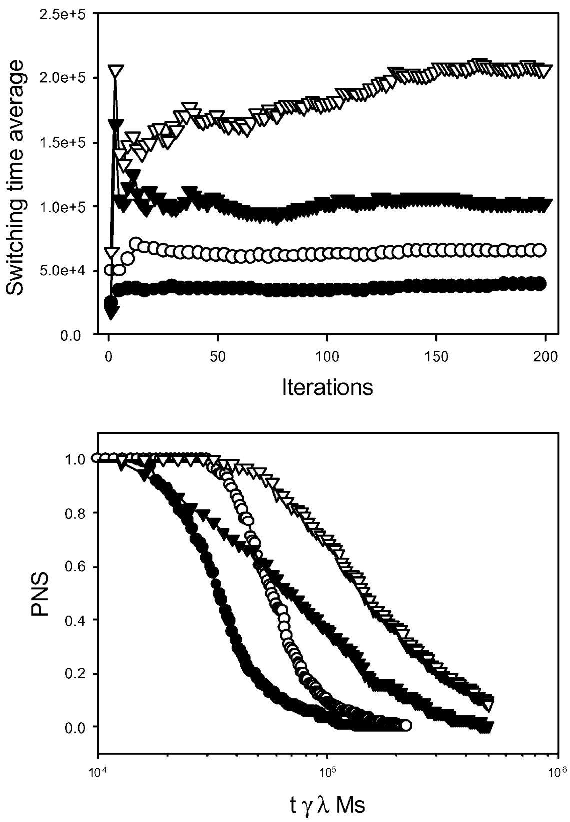

Fig. 2. (Top) Switching time average versus iteration number. (▽) 'S', $\sigma = 0.3$; (▼) 'S', $\sigma = 3.6$; (○) 'C', $\sigma = 0.3$; (●) 'C', $\sigma = 3.6$. Being $\sigma = (kT/Ms^2 V_{\text{cell}})$. (Bottom) Probability of not switching versus time. Symbols as Top.

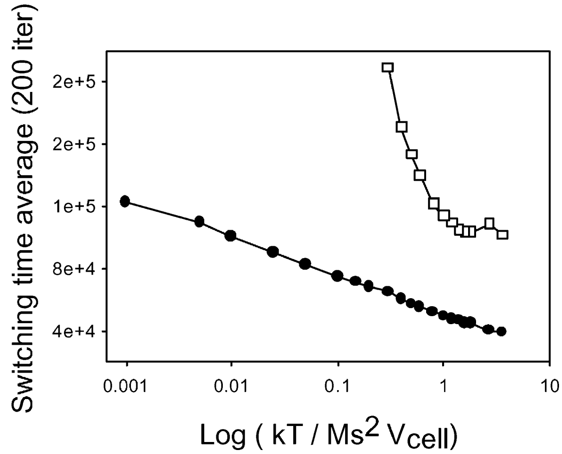

Fig. 3. Switching time average after 200 iterations versus Log ($kT/Ms^2 V_{\text{cell}}$). (□) 'S' initially magnetized nanodot. (●) 'C' initial state.

activated switching was found at most of the temperatures investigated. The 'switching time' was defined as the time elapsed from the beginning of the stochastic simulation till the moment at which the magnetization turns to the '-x' direction. In Fig. 2 (top), the averaged switching time can be observed for both 'C' and 'S' configurations; the good convergence obtained after 200 simulations is noteworthy. The switching time is found to be larger in the 'S' state, compared to 'C' at the same temperatures. Fig. 2 (bottom) presents the probability of not switching (PNS); the shape of the PNS curves is analogous to [5,6] and it can be fitted to a delayed stretched exponential. A detailed study of the relaxation parameters and its physical consequences will be published [8].

Finally, in Fig. 3 the dependence of the switching time average after 200 simulations with temperature is shown. In the 'C' configuration a clearly Arrhenius-like behavior is obtained while for the 'S' configuration a non-Arrhenius dependence is found. A careful study of the evolution of the micromagnetic magnetization prior to the thermal switching in both cases has been carried out. For the 'C' configuration the switching takes place always by the same process but in the 'S' state several different intermediate states can appear so that the switching process has various possible routes. In most of the cases the 'S' configuration first goes through a metastable more energetic 'C' configuration and then the switching is fulfilled. This results in a larger switching time and a strictly non-Arrhenius behavior in the temperature range analyzed.

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