TIME-DEPENDENT MAGNETIC SWITCHING AT PICOSECOND TIME SCALE

Jingyue MIAO[1], Dan WEI[2] and Chuan LIU[3]

1) Tsinghua Univ., Beijing, China, miujy15@mails.tsinghua.edu.cn

2) Tsinghua Univ., Beijing, China, weidan@mail.tsinghua.edu.cn

3) Peking Univ., Beijing, China, liuchuan@pku.edu.cn

I. INTRODUCTION

Recently, the thermodynamic equilibrium and nonequilibrium behavior of ferromagnetic materials have been studied extensively due to the applications in laser-induced magnetization switching in heat-assisted magnetic recording (HAMR) and all-optical switching (AOS) in the picosecond regime.

The micromagnetics simulation using Landau-Lifshitz-Bloch (LLB) equations can take the thermal activation into account by introducing a stochastic thermal fluctuation term; however, the energy minimum cannot be achieved and the length scale of thermal activation is limited to nanoscale [1], [2]. The new hybrid Monte Carlo (HMC) micromagnetics by Wei et.al [3] is a self-consistent method for the thermally dynamic magnetic studies. It can accurately describe the distribution of magnetization at temperature T by solving Hamilton equations, using Hybrid Monte Carlo algorithm to find a configuration of magnetizations $\{M_i\}$ obeying the Boltzmann-like distribution $e^{-F[\{\vec{M}_i\}]/kT}$. In hybrid Monte Carlo algorithm, the iteration of the Hamilton canonical equations follows a fictitious time τ, which is broken up into consecutive trajectories. The total iteration time is given by $\tau=N_{tra}\,N_{\mathrm{step}}\,\delta\tau$, where N_{tra} is the number of trajectories, and N_{step} and $\delta\tau$ are the number of steps in one trajectory and the duration time of each step, respectively. And if we compare the simulation results with the experiments, we can obtain the relationship between τ and the real time t.

II. RESUTLS AND DISCUSSIONS

We have studied the time-dependent coercivity in a time scale 10^{-5} to 10^{-8} s [4]. In this work, we would like to further analyze the time-dependent switching at a shorter time-scale.

A granular film with Voronoi polycrystalline structure is simulated. The film area is 24nm×24nm×3nm (with in-plane periodic boundary conditions) and divided into a regular mesh of 1nm×1nm×1nm micromagnetic cells. At 0K, in crystalline grains, the saturation M_s is 700 emu/cc, the exchange constant A^*_1 is 0.5×10^{-6} erg/cm and the anisotropy energy K is 4.2×10^{7}erg/cm^3; in the grain boundary, M'_s is 70 emu/cc, A^*_2 is 0.1×10^{-7} erg/cm and K' is 2.94×10^{7}erg/cm^3.

In a constant-field model, a constant magnetic field is applied in the opposite direction of initial magnetization M. In Fig.1, the simulated time-dependent coercivity reasonably agrees with Sharrock's law in a time scale 10^{-8}s<t<10^{-5}s with 10 to 10^4 HMC trajectories. So that in this case a trajectory ($\tau=10^{-3}$) in the HMC algorithm is roughly equal to 1 ns in the real time scale.

The fictitious time τ is broken up into consecutive trajectories, given by $\tau=N_{tra}\,N_{\mathrm{step}}\,\delta\tau$. So that the length of a trajectory varies with the parameter N_{step} and $\delta\tau$. We use two sets of parameters of N_{step} and $\delta\tau$, Set A and Set B, to simulate the magnetization switching in a same constant-field model. As can be seen in fig.2, the results show that the magnetization decay and switching follows the similar process in two different time scales. Notably, simulations with parameters of Set B have derived the conclusion that a trajectory is close to 1 ns. As a result, in the simulations with parameters of Set A, a trajectory can be inferred to be close to 1 ps from comparison. Thus we can investigate the thermodynamic magnetization switching in the picosecond regime if we put emphasis on the first hundreds or thousands of trajectories. Therefore, the HMC

Jingyue MIAO
E-mail: miujy15@mails.tsinghua.edu.cn
tel: +86 1305132620

micromagnetics can be used to study the laser-induced magnetization switching in HAMR and AOS with a reasonable approximation to the temperature profile in the process of heating and recovery as well as the accurate microstructure of the recording medium included.

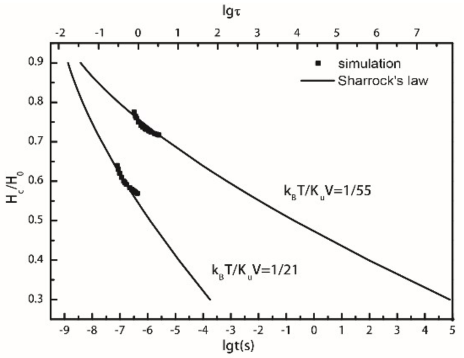

FIG. 1 Comparison of the time-dependent coercivity derived by simulation and the Sharrock's law.

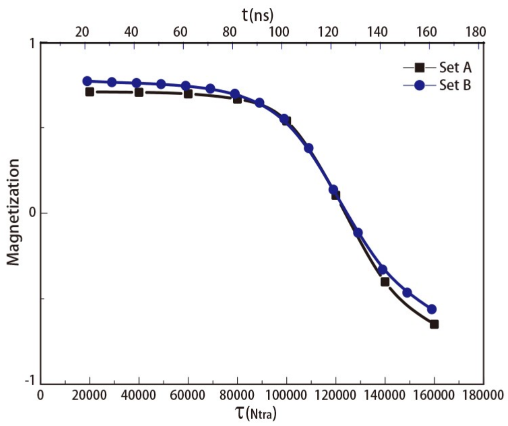

FIG. 2 Magnetization switching in two time scales. The upper horizontal axis is in a real time scale corresponding to the number of trajectories N_{tra} in model with parameters of Set B, and the under horizontal axis is in the time scale of the N_{tra} in model with parameters of Set A.

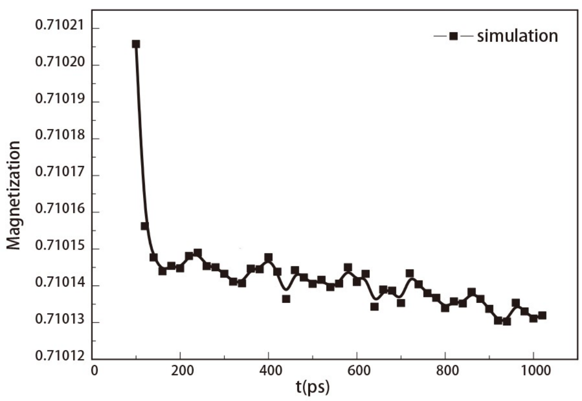

FIG. 3 Magnetization decay in the picosecond regime. The horizontal axis is in the real time scale corresponding to the N_{tra} in model with parameters of Set A.

REFERENCES

1) W. Brown. "Thermal fluctuation of fine ferromagnetic particles," *IEEE Transactions on Magnetics,* 1979, pp. 1196-1208
2) R. Skomski, P. Kumar, G. C. Hadjipanayis and D. J. Sellmyer. "Finite-temperature micromagnetism," *IEEE Transactions on Magnetics,* 2013, pp. 3229-3232.
3) D. Wei, J. Song and C. Liu. "Micromagnetics at Finite Temperature," *IEEE Transactions on Magnetics, 2016, pp. 1-8.*
4) Miao J Y, Wei D, Liu C. Micromagnetic studies of time-dependent coercivity [C]//Magnetics Conference (INTERMAG), 2017 IEEE. IEEE, 2017