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Current-Induced Magnetic Domain-Wall Motion by Spin Transfer Torque: Collective Coordinate Approach with Domain-Wall Width Variation

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1. Introduction

The spin transfer torque generated by a spin-polarized current can induce the shift of the magnetic domain-wall (DW) position. In this work, we study theoretically the current-induced domain-wall motion by using the collective coordinate approach [1] in which the authors derived the equations of motion for the collective coordinates such as the wall center position X and polarization Φ (the angle between spins at the wall center and easy plane) and analyzed the current-induced domain-wall motion (CIDWM) in terms of the collective coordinates. However, there are indications that the DW motion is usually accompanied with the DW deformation and thus it is not sufficient to describe the CIDWM using the variable X and Φ only. In this paper, we extend the collective coordinate approach, so that not only the variation of X and Φ but also the variation of the DW width λ is taken into account. Use of the three collective coordinate (X, λ, Φ) makes the description for the DW motion more detailed.

2. Results and Discussion

The motion of the DW is closely coupled with the DW deformation. When the spin transfer v_{el} proportional to the spin current is smaller than a certain critical value v_{el}^c, the spin angular momentum is completely absorbed to deform the DW and thus the wall motion stops with λ and Φ saturated within a nanosecond. When the spin transfer rate v_{el} is lager than the absorption rate to Φ and λ for $v_{el} > v_{el}^c$, the net spin transfer with nonzero drives the stream motion and the DW does not stop.

The Fig. 1 shows the possible control of the critical value for CIDWM with sample geometry. The critical value v_{el}^c is different from the TK's result [1] $v_{el}^c = SK_p\lambda_0/2\text{hbar}$, which ignores the DW width variation. We confirm that the DW width variation can reduce the critical value v_{el}^c. The effect of the DW width variation on velc becomes larger as K_p increase so that v_{el}^c becomes smaller than the TK's result as the aspect ratio decrease as shown in the Fig. 1.

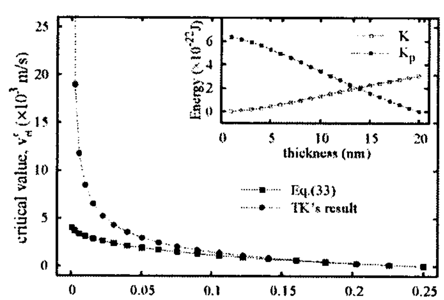

Fig. 1. The critical value v_{el}^c as function of aspect ratio (=t/W where t is thickness and W is width) of nanowire with constant cross-sectional area, A=1600nm^2 where the transverse wall is stable. The inset shows relation between the easy axis anisotropy K, the hard axis anisotropy K_p and the thickness t.

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Effect of the Thermal Conductivity of Substrate on the Temperature of Nano-wire for Current Induced Domain Wall Motion

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Spin transfer torque is an exciting physical phenomenon which has great potential for the application of spintronics devices. When the spin polarized current flow through a magnetic domain wall, the domain wall absorbs the spin angular momentum of the conduction electrons. It causes the motion of the domain wall, which is called CIDWM (current induced domain wall motion). The CIDWM observation is required high current density, and the Joule heating is always accompanied. Therefore the information of the temperature of the nano-wire is important not only to understand spin dynamics, but also for the device applications.

In most CIDWM experiments, thick SiO_2 is employed as an insulator layer due to its excellent electric insulation property. However, we find that the SiO_2 is the worst one for the CIDWM application due to its poor thermal conductivity. According to the analytic expression for the temperature of the nano-wire [1], it strongly depends on the thermal property of the substrate. In this study, we investigate the dependence of the temperature of the nano-wire on the thermal properties of the substrates such as thermal conductivity, heat capacity, and diffusivity by finite element method with commercial software [2]. The size of nano-wire is fixed as 350 nm×10 nm and infinitely thick insulator layers such as SiO_2, Al_2O_3, and Si_3N_4 are treated as substrates. The thermal conductivities of SiO_2, Al_2O_3, and Si_3N_4 are 1.4 W/mK, 35 W/mK, and 20 W/mK, respectively. It is clearly shown in Fig. 1, the temperatures of the nano-wire strongly depends on the substrates. Even with the same current density (10^{12} A/m^2), the peak temperatures are changed from 280 K to 427 K for Al_2O_3 and SiO_2, respectively. With the results of our study, Al_2O_3 or Si_3N_4 are superior to SiO_2 for the insulator layer of the CIDWM experiment.

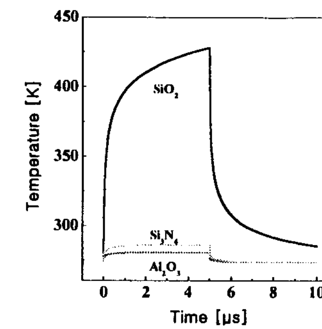

Fig. 1. Temperature of the nano-wire on the various substrates as a function of the time.

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