Current-induced gyration of single skyrmion confined in a nanodisk

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1. Introduction

Recent micromagnetic simulation studies have suggested that a single magnetic skyrmion can be nucleated and stabilized in a nano-sized magnetic disk in the presence of Dzyaloshinskii-Moriya interaction (DMI) [1, 2]. Based on these previous works and micromagnetic simulations, we observed skyrmion gyrotropic motion in a nanodisk by applying sinusoidal oscillating current. Throughout this study, we assume that spin Hall effect (SHE) is the main force to drive skyrmions. These works help us to understand skyrmion dynamics induced by alternating current (AC).

2. Simulation Scheme

We conducted simulations of skyrmion gyrotropic motion using the OOMMF code[3] with the DMI extension code[2]. In this study, we consider an ultrathin, 0.6-nm-thickness magnetic circular disk with 80 nm diameter, sandwiched by a heavy metal of large spin-orbit interaction and nonmagnetic insulator. We assume material parameters as follows; saturation magnetization M_s=1.13×10^{6}A/m, exchange stiffness constant A=1.6×10^{-11}J/m, DMI constant D=3.0×10^{-3}J/m^2, perpendicular magnetocrystalline anisotropy energy K_u=1.28×10^{6}J/m^3, and damping constant a-0.015. The mesh size is 1.0×1.0×0.6nm^3.

In terms of driving force, we assume that the skyrmion is driven mainly by SHE, namely spin-orbit torque (SOT) and other driving forces such as spin transfer torque (STT) and external magnetic field are not considered. The governing equation is the Landau-Lifshitz-Gilbert equation with SOT as follows,

$$\frac{\partial \vec{m}}{\partial t} = -\gamma_0 \vec{m} \times \vec{H}_{\text{eff}} + \alpha\, \vec{m} \times \frac{\partial \vec{m}}{\partial t} + \gamma_0 \vec{m} \times \left(\vec{m} \times H_{\text{SHE}} \sin(2\pi f t)\, \vec{e}_y \right) \quad (1)$$

where $\vec{m} = \vec{m}(t, x)$ is the dimensionless unit vector of local magnetization, γ_o is the gyromagnetic ratio (=2.21×10^5(A/m)$^{-1}$s^{-1}), f is the frequency of sinusoidal alternating current, H_{eff} is the effective magnetic field which derives from exchange, anisotropy and DMI energy terms. The third term of the right side of the equation (1) indicates the SOT term assuming that the oscillating current is applied along x direction and H_{SHE} is a time-independent parameter defined as below[4],

$$H_{\text{SHE}} = \frac{\hbar \theta_{SH} j_a}{2\mu_0 e M_s t_z} \quad (2)$$

where θ_{SH} is the spin Hall angle of the adjacent heavy metal layer, μ_o is the permeability of vacuum, e is the elementary charge, t_z is the thickness of the magnetic layer (t_z= 0.6 nm in our simulations), and j_a is the amplitude of oscillating current density flowing in the heavy metal layer.

3. Result and Discussion

We observed gyration motion of the single skyrmion induced by harmonic oscillating current along *x*-axis. Figure 1 shows the trajectory of the gyrotropic motion of a skyrmion with driving frequency of f=6.0GHz and amplitude H_{SHE}=2.69×10^{4}A/m which is equivalent to j_a=6.96×10^{11}A/m^2 with θ_{SH}=0.1. Here the gyration frequency is 0.32 GHz.

Also we observed that the skyrmion periodically repeated shrinking and swelling during its motion. Figure 2 shows the time dependence of the skyrmion size. It is remarkable that the graph indicates the beginning of steady gyration clearly and the period of the size fluctuation is 6.32 GHz, which is different from the driving frequency 6.0 GHz.

In terms of the characteristic frequencies, i.e. driving frequency, gyration frequency and size-oscillation frequency, we found that the following relation :

driving resonant frequency =size oscillation frequency - gyration frequency.

And this relation satisfies for various values of D=2.4, 2.7, 3.0 mJ/m^2.

This relation might be a clue to understand the resonance effect of skyrmion gyration.

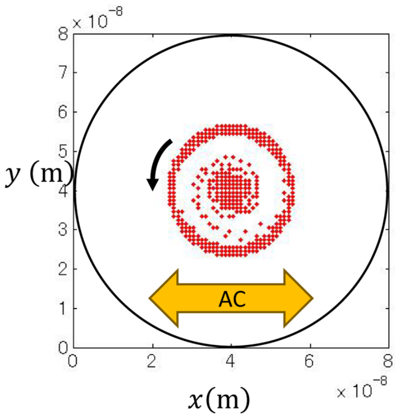

Fig. 1. The trajectory of single skyrmion gyration. The resonant frequency is 6.0 GHz for =3.0 *mJ/m*^{2}.

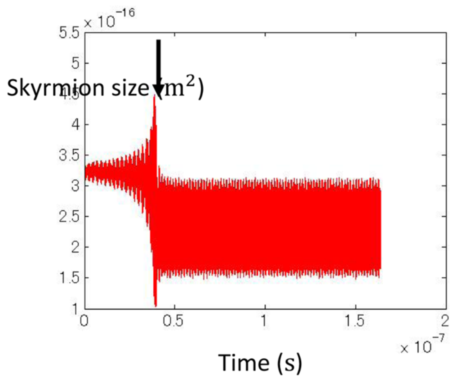

Fig. 2. Skyrmion size vs. time. The bold arrow indicates the start of the steady gyration. During the steady gyration, the skyrmion size is altered periodically and the frequency is 6.3 GHz for D=3.0 *mJ/m*^{2}.

4. References

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