Phase diagrams of the stable skyrmion with Dzyaloshinskii-Moriya interaction

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1. Introduction

Magnetic skyrmions are topologically stable spin textures. Recently, a single magnetic skyrmion is of considerable interest because of its rich physics and potential for information carrier in storage devices [1, 2]. In this work, we study a single skyrmion generated by Dzyaloshinskii-Moriya (DM) interaction [3, 4], and provide phase diagrams with various parameters. The DM interaction, the antisymmetric exchange interaction, is caused by the broken inversion symmetry with the spin-orbit coupling (SOC). We use the interfacial DM interaction that is present at the interface between a ferromagnet and a normal metal with strong SOC. Based on micromagnetic simulation, we find condition for the stable single skyrmion. Sampaio et al. [5] reported the phase diagram of an isolated skyrmion in nanodisks. However, the phase diagram of a single skyrmion in nanowires has been not reported yet. This work will be useful to design nanowires, for use of the single skyrmion.

2. Method

We solve Landau-Lifshitz-Gilbert equation, given as

$$d\mathbf{m}/dt = -\gamma\, \mathbf{m}\times\mathbf{H}_{eff} + \alpha\, \mathbf{m}\times d\mathbf{m}/dt, \quad (1)$$

where **m** is the unit vector along the local magnetization, γ is the gyromagnetic ratio (= 1.76×10^7 Oe^{-1} sec^{-1}), α is the damping constant (= 0.3), and $\mathbf{H}_{eff}$ is the effective magnetic field including the exchange, anisotropy, magnetostatic, and DM fields.

To construct phase diagrams, we vary the DM constant D (0 to 9 erg/cm^2), the perpendicular anisotropy energy density K_u (0.1 to 1.9 $\times$ 10^7 erg/cm^3), the exchange stiffness constant A_{ex} (= 1.5 $\times$ 10^{-6} erg/cm), the saturation magnetization M_s (= 580 emu/cm^3), the thickness (= 0.4 nm), and the width (= 40 nm) of nanowire. The cell size is $1\times1\times0.4$ nm^3. We also construct phase diagram for nano squares. The width and length of the nano square are the same (= 40 nm).

3. Result

We define several magnetic configurations as shown in Fig. 1.

Phase diagrams as functions of D and K_u for nanostructures are shown in Fig. 2 (a) and, (b). Here, we use Aex of 1.5 $\times$ 10-6 erg/cm, and M_s of 580 emu/cm^3. We obtain several distinct regions; the uniformly magnetized state (stable FM) is stable (in blue), a single skyrmion is stable (in green), and distorted magnetized array is obtained (in yellow).

By comparing Fig. 2(a) and Fig. 2(b), one finds that a stable skyrmion region in nano square is much wider than in nanowire. We attribute this difference to the confinement effect due to the pattern shape. In nanowires, the confinement exists only in the y-direction, but In nano squares, the confinement exists in both x- and y-directions.

4. Conclusion

Based on micromagnetic simulation, we investigate the phase diagram of a single skyrmion in nanowire and nanosquare. We find that the single skyrmion phase is obtained more easily for the case with higher perpendicular anisotropy, higher DM interaction.

Our result will be helpful in order to design materials and devices of a single skyrmion in a nanowire.

5. reference

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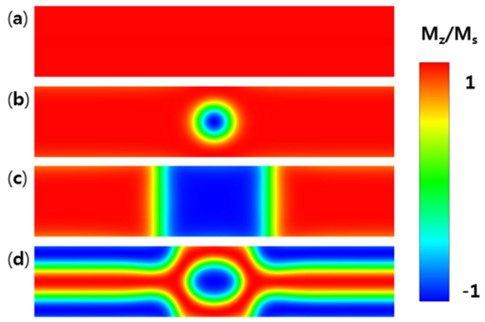

Fig. 1. Definition of each magnetic state. (a) is uniformly magnetized state, (b) is stable skyrmion state, (c) and (d) are distorted shape state.

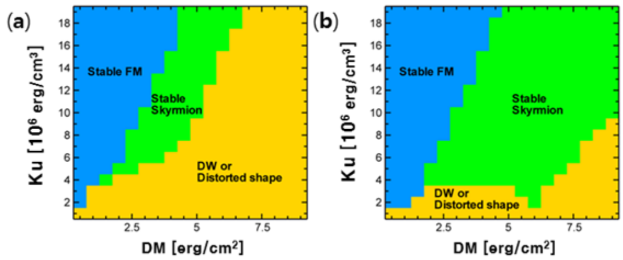

Fig. 2. D (DM interaction) - K_u (perpendicular anisotropy) phase diagrams of (a) nanowire and (b) nanosquare. Here we use A_{ex} of 1.5×10^{-6} erg/cm and M_s of 580 emu/cm^3.