A Magnetization Process Analysis Using Simplified Domain Structure Model

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I. Introduction

The micromagnetic simulation based on the LLG equation is a powerful tool to analyze microscopic behavior of magnetic materials. However, it is difficult for the micromagnetic simulation to describe mesoscopic or macroscopic magnetic behavior because of its high computational cost. Several domain structure models (DSMs) [1]-[4] have been proposed to represent mesoscopic behavior of magnetic materials. This study simplifies the DSM to reveal basic mechanism of magnetization process.

II. Domain Structure Model

The DSM consists of several domains with uniform magnetizations and their boundaries (domain walls). The magnetization state is given by the local minimization of total magnetic energy. The simplified DSM assumes that the magnetostatic field $\boldsymbol{H}_{st}$ is given as

$$\boldsymbol{H}_{st} = -k\,\boldsymbol{M}_{ave} \tag{1}$$

where $\boldsymbol{M}_{ave}$ is the average magnetization and k is a demagnetization factor.

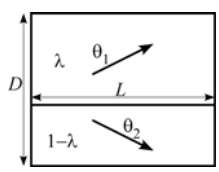

Fig. 1. Two domains.

This article examines magnetization process of thin material with two domains as shown in Fig. 1 where (θ_1, θ_2) are the rotation angles of magnetization vectors, (λ, $1-\lambda$) are the volume ratios of magnetic domains, L is the domain wall length, and D is the material width. The energy components are normalized by the anisotropic energy as

$$e_{an} = \lambda \sin^2\theta_1 + (1-\lambda)\sin^2\theta_2 \tag{2}$$

$$e_{ap} = -h\,\{\,\lambda\cos(\theta_1-\theta_{ap}) + (1-\lambda)\cos(\theta_2-\theta_{ap})\,\} \tag{3}$$

$$e_w = w\,\{\,1-\cos(\theta_1-\theta_2)\,\}^2 \tag{4}$$

$$e_{st} = s\,\{\,\lambda^2 + 2\lambda(1-\lambda)\cos(\theta_1-\theta_2) + (1-\lambda)^2\,\} \tag{5}$$

$$h = 2H_{ap}/M_S/\kappa\ ,\ w = l_{ex}(\kappa+1)^{1/2}/\kappa/D\ ,\ s = k/\kappa\ ,$$
$$\kappa = 2K_1/\mu_0 M_S^2\ ,\ l_{ex} = (2A/\mu_0 M_S^2)^{1/2} \tag{6}$$

where e_{an}, e_{ap}, e_w, and e_{st} are the normalized energy density of anisotropic energy, Zeeman energy, domain wall energy, and magnetostatic energy, respectively; H_{ap} is the applied magnetic field, θ_{ap} is its direction, M_S is the magnitude of spontaneous magnetization, K_1 is the anisotropy constant, and A is the exchange stiffness constant. The unknown variables (θ_1, θ_2, λ) are determined so as to minimize the total energy locally.

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III. Magnetization Process Analysis

Magnetization curves are obtained with the variation of h. Fig. 2 shows MH curves when (θ_{ap}, w, s) = (5°, 1, 0.5), (5°, 0.2, 6) where normalized average magnetization $m_x = \lambda\cos\theta_1 + (1-\lambda)\cos\theta_2$ is plotted. Solid lines mean solution curves of local energy minima (stable solutions) while dashed lines are for other solutions (local maxima and saddle points). When the effect of domain wall energy (w) is large and that of magnetostatic energy (s) is small, single domain type magnetization appears as shown in Fig. 2(a). When w is small and s is large, gradual magnetization appears as in Fig. 2(b). The linear magnetization for small h in Fig. 2(b) results from the 180° domain wall motion of which solution is given as

$$4s\,(\,\lambda - 1/2\,) - h\cos\theta_{ap} = 0\ . \tag{7}$$

Fig. 3 illustrates the domain structures for (θ_{ap}, w, s) = (5°, 0.2, 6). The 180° domain wall motion is seen for small h whereas large h induces the rotation of magnetization.

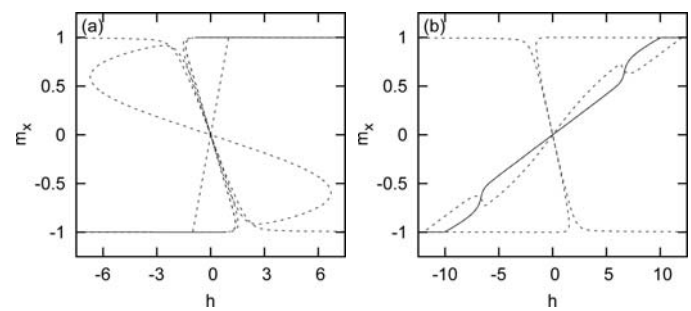

Fig. 2. Magnetization curves.

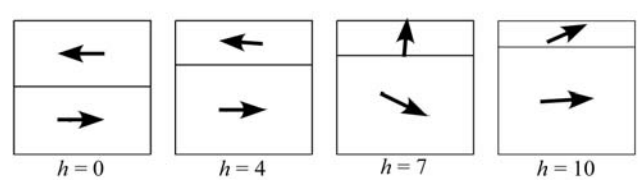

Fig. 3. Domain structures obtained by the simplified DSM.

References

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