NONUNIFORM MICROMAGNETIC STATES IN THIN ELLIPTICAL PARTICLE

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For the thin film with dimension smaller than submicron, both the magnetostatic energy and exchange energy are considerably crucial in determining the magnetization structures. Experimentally, many factors, such as the shape, grain size, the direction of anisotropy, the magnetization history, the boundary roughness, influence the magnetization structures. Undoubtedly, the element sizes [1] and shapes are the prior factors in our considerations for studying the magnetization structures of nanostructured thin films. In this digest we describe a new stable state which explains naturally the evolution from quasiuniform to vortex state with increasing of the dimension.

The material parameters of Permalloy particle (saturation magnetization $M_s = 800 \text{ emu/cm}^3$, exchange constant $C = 2A = 2 \cdot 10^{-6} \text{ erg/cm}$, uniaxial anisotropy constant $K_1 = 10^3 \text{ erg/cm}^3$) are used in our numerical simulations. The particle is divided into an array of small uniformly magnetized cubic cells with the size 3 to 5 nm, small enough compared to the exchange length of the material, $R_0 = C^{1/2}/M_s = 17.7 \text{ nm}$. Stable magnetization configurations are derived by time integration of the Landau-Lifshitz-Gilbert (LLG) equation [2].

Thin elliptical particle with thickness $L_z = 12, 18, 24, 30$ and 36 nm , and with diameters $D \leq 210 \text{ nm}$ are investigated by the numerical simulation. The energy diagram of various stable magnetization states existing in cylindrical particle with thickness $L_z = 18 \text{ nm}$ is shown in Fig. 1 as a typical example. For small enough diameter, $D < D_{c1}$, a quasiuniform state (flower state) has a lowest total energy. Therefore, D_{c1} can be considered as effective single-domain diameter of cylindrical particle. One can see in Fig. 1 that the flower state remains stable up to another critical diameter, $D_{c1} > D_{c1}$. At $D > D_{c1}$ a bending type state develops gradually with increase in particle size. This state is denoted as BS 1 in Fig. 1. In contrast to the flower state, the magnetization of the bending state diminishes considerably as function of particle diameter. In turn, the BS 1 state becomes unstable at a critical diameter D_{c2} due to large curvature of the magnetization near the lateral side of the particle. This new instability leads to entering of the vortex inside the particle. As Fig. 1 shows, for thickness $L_z = 18 \text{ nm}$ another stable bending type state, BS 2, with large in-plane magnetization is revealed numerically at larger diameters, $D \geq D_{c3}$. However the BS 2 state is absent for thickness $L_z \geq 24 \text{ nm}$. It is important to note also that the critical diameters D_{c1} and D_{c2} reduce gradually with increase in the particle thickness. Furthermore, there is no stable state

with appreciable in-plane magnetization in cylindrical Permalloy particle with thickness $L_z \geq 36 \text{ nm}$.

For elliptical particle the numerical simulations were carried out for fixed thickness $L_z = 30 \text{ nm}$, but for various aspect ratios, $1 \leq L_x/L_z \leq 4$. In addition to different vortex patterns studied earlier [3], stable bending states are obtained for elliptical particle with sufficiently large in-plane dimensions. Similar to the case of cylindrical particle the bending state in elliptical particle arises due to instability of the quasiuniform magnetization at certain critical transverse diameter. The latter depends on the particle aspect ratio. It is found that the average magnetization of the bending state decreases considerably as function of the particle size at fixed aspect ratio. Eventually the bending state becomes unstable at another critical diameter where one or several vortices nucleate. The nucleation of the vortices occurs at the lateral side of the particle near the points where demagnetizing field reaches the value high enough to rotate the unit magnetization vector out of the particle plane. This process leads to a creation of a precursor of the vortex core at the lateral side of the particle. Later the vortex core moves gradually inside the particle forming a one-vortex or multi-vortex pattern. Therefore, the bending states provide continuous transformation of the quasiuniform magnetization into the vortex pattern with increase in the particle size. It should be noted, however, that the bending state is not a transient state. It can be stable in some intermediate range of sizes depending on the particle aspect ratio. It is found that for elliptical particle with thickness $L_z = 30 \text{ nm}$ the ranges for stability of quasi uniform and bending states increase rapidly as function of the particle aspect ratio.

References

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