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Study of magnetic properties for co double-nanorings: Monte Carlo simulation

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ABSTRACT

In this paper, cobalt double-nanorings (Co D-N-rings) structure model was constructed. Based on Monte-Carlo simulation (MC) method combining with Fast Fourier Transformation and Micromagnetism (FFTM) method, the magnetic properties of Co D-N-rings with different geometric dimensions have been studied. The simulated results indicate that, the magnetization steps in hysteresis loops is the result of the special spin configurations (SCs), i.e., onion-type state and vortex-type state, which are very different from that in many other nanostructures, such as nanometer thin-films, nanotubes, etc. Besides, Co D-N-rings with different geometric dimensions present interesting magnetization behavior, which is determined by the change of both SCs and exchange interaction in Co D-N-rings.

1. INTRODUCTION

Recently, nano-scale magnetic materials have drawn much attention in condensed matter physics field due to the requirement of device miniaturization and their abundant physics propertie, [1-3] such as spin wave in NiFe/Co two-dimensional magnetic crystals, [4] YIG ferromagnetic ultrathin films, [5] magnetism in nanocluster and nanoring metamaterials operating at optical frequencies, [6] and so on. Among these nanostructures, disk-shape thin films are more suitable to be magnetic recorder for they can effectively prevent the formation of edge domains, and reduce stray magnetic field, [7,8] However, there is high-energy vortex at the centers of disk-shaped nano films when the system is in vortex-type, which makes the magnetization switch more difficult. [9] Therefore, new nanostructures based on ring-shape magnetic materials, such as Ni, Co, Fe and permalloy alloy magnetic nanorings, [10–12] were provided and had been well investigated in both theoretical and experimental aspects. [13–19] The sizes, structure and the distance between two nanorings can much influence the physics properties of the nanoring materials. Therefore, we can simulate the real nanostructure materials with different elements and structure parameters, and predict their physics properties by theoretical computation methods. In this paper, we proposed a double-nanorings structure (named as D-N-rings) to construct cobalt (Co) nanometer thin film. Based on Heisenberg model, the magnetization dynamic properties of the Co D-N-rings with different geometric parameters were studied by using Monte Carlo (MC) simulation technology combining with Fast Fourier Transformation and Micromagnetism (FFTM) method. [20,21]

2. MODEL AND SIMULATION METHOD

Co D-N-rings model was constructed, as presented in Fig.1. The geometric dimensions are marked as following parameters: The outside radius (r_{out}) of each single ring is set as 100 nm in all the cases. Both inside radius (r_{in}) of single ring and center distance of the two rings (d_c) can be changed in the simulation investigations.

The Hamiltonian of general magnetic materials can be described by,

$$E = -\sum_{ij} J\mathbf{S}_i\mathbf{S}_j + D\left[\frac{\mathbf{S}_i\mathbf{S}_j}{r_{ik}^3} - 3\frac{(\mathbf{S}_i r_{ik})(\mathbf{S}_j \mathbf{r}_{ik})}{r_{ik}^5}\right] - Kv_0\sum_i (\mathbf{S}_i\mathbf{u}_i)^2 - M_s v_0 H\sum_i \mathrm{S}_i\mathbf{h} \quad (1)$$

where the right side of the equal sign presents several competing energies: exchange energy, dipolar interaction, magneto-crystaline anisotropy, Zeeman energy. Here, we also use the expression to be the Hamiltonian of Co D-N-rings. In this

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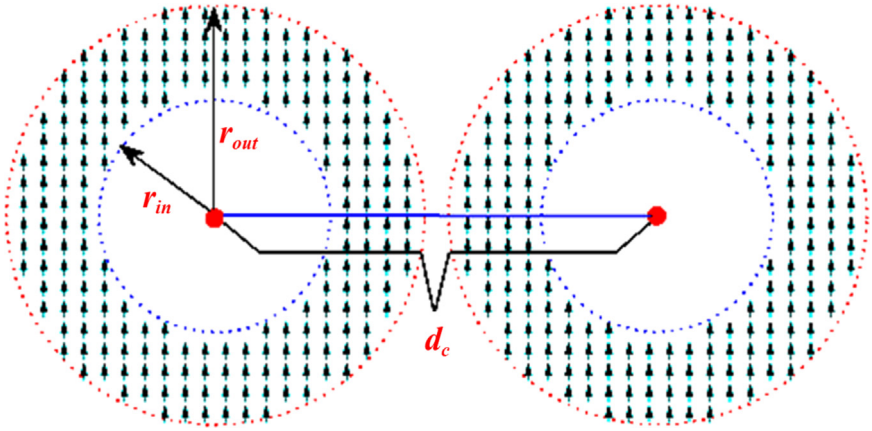

Fig. 1. The geometric model of the Co D-N-rings.

expression, the exchange integration J is equal to $2Ad_1\pi/6$, where d_1 is the distance between two nearest discretization cells, and A is the exchange constant. The dipolar interaction parameter D is equal to $(M_s\nu_0)^2/2$, where M_s is saturation magnetization and ν_0 is the volume of the discretization cell. The parameter D presents the strength of the dipole-dipole interaction. K is the magnetocrystalline anisotropy constant. In simulation, we combined MC simulation with FFTM method to calculate the magnetic properties of the Co D-N-rings. In the simulation, according to the real magnetic parameters of Co, the constants in the Hamiltonian are set as following, $d_1=10$ nm, $A=1.3\times10^{-11}$ J/m, $M_s=1.43\times10^6$ A/m. Here, $K=0$ because multicrystal Co D-N-rings are considered. Besides, the spins are suggested to rotate freely in three dimensions. In all the cases, the external magnetic field is applied along x-direction (in plane) and varies from -2000 Oe to 2000 Oe. Based on the aforementioned model and method, we systematically calculate the hysteresis loops and spin configurations (SCs) of Co D-N-rings with different geometric structure parameters, including r_{in} and d_c.

3. RESULTS AND DISCUSSION

We simulated the magnetization behavior of the Co D-N-rings with different geometric parameters. First, the effect of different r_{in} on the magnetic properties was considered. The simulation

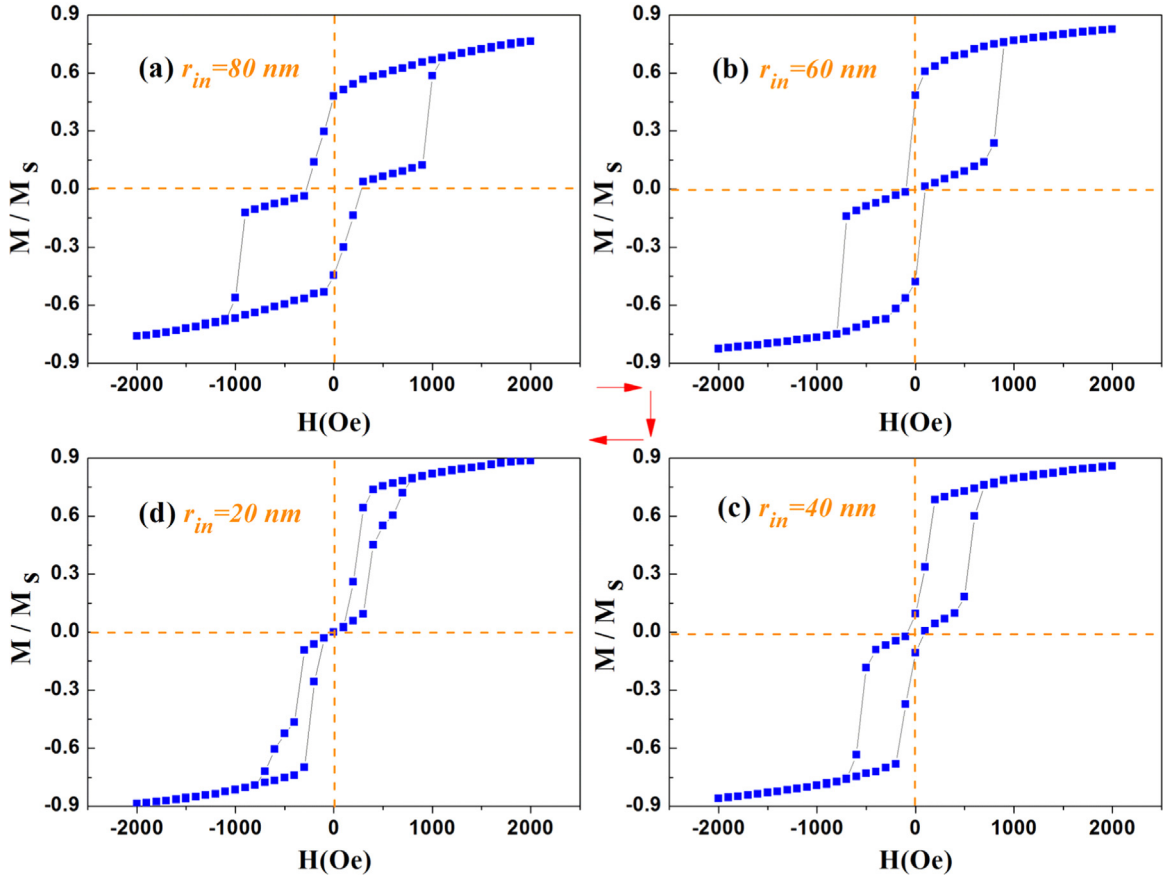

Fig. 2. Magnetic hysteresis loops of Co D-N-rings. with different r_{in} and $d_c=220$ nm and $r_{out}=100$ nm.