MFM STUDY OF VORTEX STATE IN FERROMAGNETIC NANOPARTICLES

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Ordered arrays of ferromagnetic nanoparticles are actively studied currently, because of their potential applications as media for ultrahigh density magnetic storage devices. The interest to the magnetic vortex states in ferromagnetic nanoparticles (vortex particles) are motivated by the bistability of this system (clockwise and counterclockwise magnetic structures). These two vorticity directions can be used for recording a bit of information. The prospective usage of vortex states for data storage is accounted for by the absence of magneto static interaction between adjacent particles, which limits of magnetic recording densities for the ordinary single domain systems. In present work we report about our experiments to obtain process control for vorticity directions in nanomagnets by magnetic force microscope.

Arrays of nanomagnets (Fig.1a,b) were formed by electron-beam lithography from cobalt films. For the fabrication of particles we have used nanolithographic process recently developed by us with fullerene (C_{60}) films as negative electron resist [1]. The double-layer mask containing the C_{60} film as a sensitive layer and Ti film as a transmitting layer is used to this procedure. The delicate successive plasma etching with freon atmosphere and Ar^+ ion milling are the ended steps of fabrication magnetic particles. With this way it is possible to form nanomagnets with smallest lateral length of about 20 nm and height equal to the thickness of the original metallic film. In this research we have studied elliptical particles with lateral lengths in the range from ~ 150 nm up to ~ 600 nm. The observation mode of magnetic vortexes, shape and dimensions of particles under study we chose in accordance with opportunity to detect of vorticity direction. There are two easy methods to image magnetic vortex experimentally: Lorentz transmission electron microscopy [2] and magnetic force microscopy (MFM). The first method provides better spatial resolution for magnetic images, but one needs to use superthin transparent substrates. On the other hand MFM provides a unique opportunity to modify magnetic state of particles by MFM probe. To find the vorticity direction we simulated an MFM images of the vortex particles, using the OOMMF micromagnetic simulation package [3] (Fig. 2). These data allow us to determine vorticity from the MFM image of particles in a zero applied magnetic field (given magnetization direction of the MFM probe). By applying an external magnetic field (Fig. 1c, 2c) we can test the direction of vorticity. We experimentally revealed the existence for a threshold thickness of Co particles. The single domain magnetic dipole is stable, if the thickness of elliptical nanomagnet is less than 27 nm. The remanent magnetization of particles is vortex or multivortex states, if their heights are larger than a threshold thickness. This value is well agreed with the exchange length of cobalt. We have also developed the process of magnetization reversal (clockwise vortex ⇔ counterclockwise vortex, Fig.3). As our MFM experiments show, the character of the remagnetization processes largely depends on nanomagnet geometry, the magnetic moment of the probe and lift height during scanning. One of the interesting results of investigation is the opportunity to use our particles for basic research of nanomagnetism. The system of single vortex particles is very convenient object for investigations phenomena of magnetic chirality. By MFM measurements we have studied a correlation between the core direction of magnetic vortex and sign of rotation one. Our first experiments show that there is no difference between the right- and left-hand states of magnetic vortexes. The statistics of the clockwise and counterclockwise states is about (0.49±0.02)/(0.51±0.03). However, the symmetry of the two vortex states is able to be broken at low temperature or for vortex particles with smaller size.

This work was supported by the RFBR (Grant 04-02-16827), INTAS (03-51-6426) and ISTC (2976).

References

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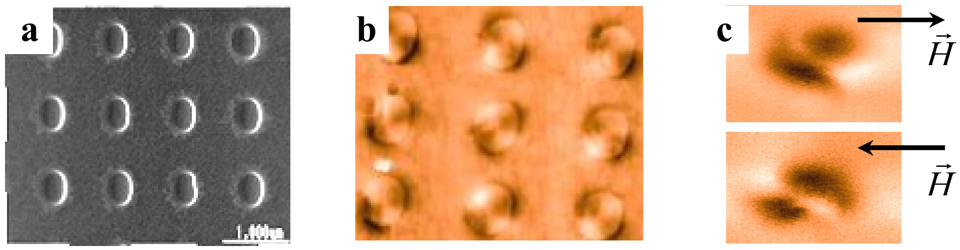

Fig.1. SEM (a) and MFM (b,c) images of Co particles. (c) – experimental MFM image of magnetic vortex in external magnetic field.

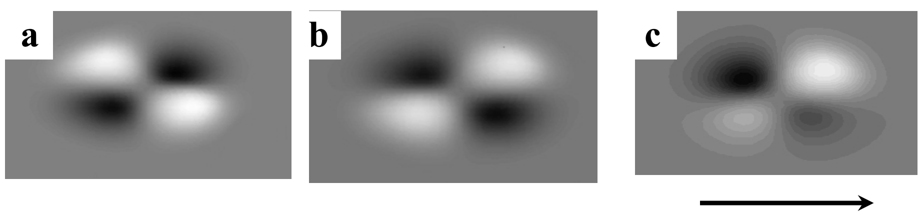

Fig.2. Simulated MFM images of vortex with clockwise (a) and counterclockwise (b) states; (c) - simulation of MFM image of vortex in external magnetic field.

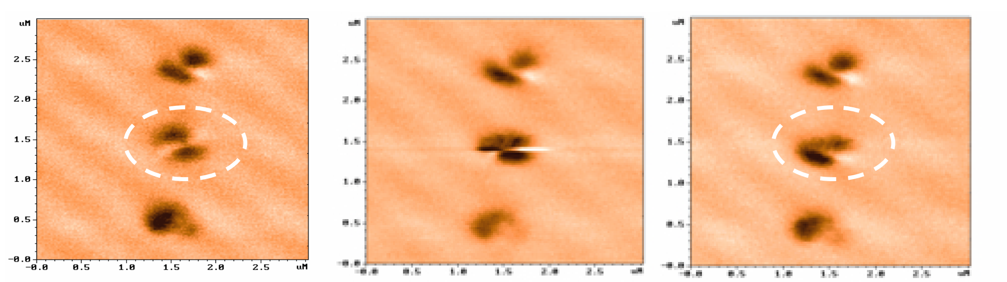

Fig.3. Change of vorticity direction within Co nanomagnet