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імені ТАРАСА ШЕВЧЕНКА

EQUILIBRIUM MAGNETIZATION STRUCTURES IN PERMALLOY HEMISHERICAL NANOPARTICLES

Denis D. Sheka, Anton Y. Vidil*

Taras Shevchenko National University of Kyiv, 2 Glushkov av., build. 5, 03127, Kyiv, Ukraine

*Vidil_Anton@ukr.net

The ground state of the magnetization distribution is studied numerically for the ferromagnetic structure on a spherical shape substrate. Two kinds of geometries are considered. (i) In the case of horizontally truncated hemisphere there exist three magnetic phases: quasiuniform easy-plane phase, the onion one and topologically nontrivial vortex one. (ii) In the case of vertically truncated hemisphere, three phases can be realized: the easy-axis phase, the onion one, and the vortex one. The phase diagram is systematically analysed in a wide range of geometrical parameters.

Recent advances in nanotechnology have made it possible to fabricate various low-dimensional systems with complicated geometry. Magnetic nanodisks, rings, stripes, and nanowires are among the most actively studied nanosystems. Magnetization configuration of nanoparticles can be very nontrivial: a magnetization curling occurs due to the dipole-dipole interaction. In particular, the vortex state is realized in a disk shaped particle, where the magnetization becomes circular lying in the disk plane in the main part of the sample, which possesses the flux-closure state. At the disk centre there appears an out-of-plane magnetization structure (the vortex core, typically 10-25 nm) due to the dominant role of exchange interaction inside the core [1]. The vortex state of magnetic nanodots has drawn much attention because it could be used for high-density magnetic storage, ultrafast magnetic memory (vortex random access memory) and miniature sensors [1]. The vortex state in nanoparticles can be realized for the dot size in the submicron range, which is much more than the minimum nanoparticle size, currently used in experiments. In order to decrease the minimal size of the vortex state particle one can treat other geometries. In particular, the ring shape geometry provides more stable pure planar vortex state nanodot with smaller critical size of the dot [2]. Another very attractive nanodot geometry is a sphere; it plays a key role in bottom-up design for fabricating new materials. Very recently, ferromagnetic films were grown on a curved (spherical) nonmagnetic surfaces. In particular, there were fabricated in Ref. [3] artificial structures of Co/Pt multilayers deposited onto an etched particle array; in Ref. [4] Co–Pt alloy films grown on self-assemblies of spherical SiO_2 particles. Such magnetic structures demonstrate nontrivial hysteresis properties [4,5]. To understand hysteresis and other magnetic properties of such structures one needs to analyse, first of all, the equilibrium magnetisation distribution in such spherical nanodots.

The aim of the current study is to provide the systematic analysis of the ground state of magnetic structure on a spherical shape substrate. Two kinds of geometries are considered: (i) the horizontal truncated hemisphere and (ii) the vertical one, see the top row of Fig. 1. The last case is more appropriate for current experiments [3,4]. In order to analyse the magnetic structure we performed the numerical computer simulations using a public-available three-dimensional OOMMF micromagnetic simulator code with material parameters of Permalloy. Numerically we solved the Landau -Lifshitz equation for the specified geometries and different types of initial magnetization distributions: the uniform easy-axial distribution, the uniform easy-plane, the vortex distribution and the random one. Typically all initial distributions finally lead to different locally stable curling states, corresponding to the energy minimum; while the global energy minimum is provided by the ground state. Following such a scheme we constructed diagrams of equilibrium magnetization distribution (phase diagram) for two geometries, see Fig. 1 (bottom row).

The phase diagram consists of three phases. The general properties of the diagram are as follows. Let us start with horizontally truncated hemisphere, see Fig. 1(a). The equilibrium magnetization of the very thin film forms the onion state, where the magnetization distribution is oriented along the hemisphere surface. Such a state becomes preferable due to the magnetostatic energy of the hemisphere. When the thickness increases we can switch to the quasiuniform easy-plane state, magnetized along the truncation plane; this state is provided by the magnetostatic charges of the ring. When the particle diameter increases the magnetization curling takes place, resulting in a vortex ground state. Energetic analysis shows that the vortex state particle is degenerated with respect to the vortex polarity, similar to case of disk-shape particles. Such a state minimizes the magnetostatic energy of the particle.

Similarly, the phase diagram of the vertically truncated hemisphere contains the onion state and the vortex one. The ground state of thick particle with small diameter is almost uniform easy-axis state. On the base of a triple point analysis we conclude the lower bound of the vortex-state hemisphere is smaller in comparison with a disk.

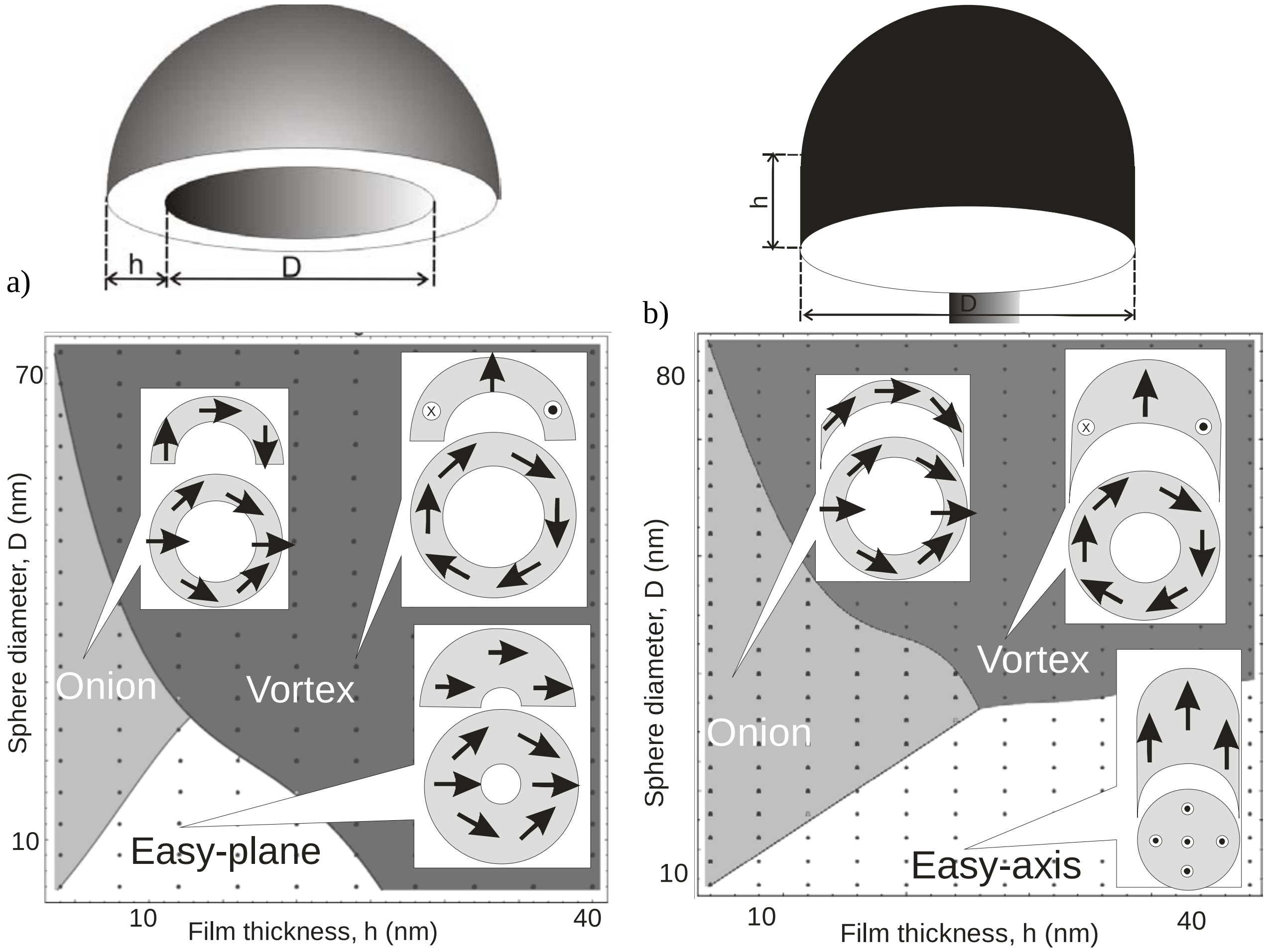

Fig. 1. The phase diagram of magnetic ground states for: a) horizontally truncated hemisphere and b) vertically one. The schematic of the structure is shown on the top row; the bottom row represents the simulations data.

References:

[1] A. Hubert, R. Schäfer, Magnetic Domains, Springer, Berlin, 1998.
[2] V. P. Kravchuk *et al*, J. Magn. Magn. Mater., **310**, 116 (2007).
[3] C. Brombacher *et al*, Nanotechnology, **20**, 105304 (2009).
[4] D. Makarov *et al*, J. Appl. Phys., **106**, 114322 (2009)
[5] M. Albrecht *et al*, Nat. Mater., **4**, 203 (2005)