Journal of Magnetism and Magnetic Materials 324 (2012) 637–641

Contents lists available at SciVerse ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Micromagnetic simulation of Fe asymmetric nanorings

J.L. Palma [a], C. Morales-Concha [a], B. Leighton [a], D. Altbir [a,b], J. Escrig [a,b,*]

[a] Departamento de Física, Universidad de Santiago de Chile (USACH), Avda. Ecuador 3493, 917-0124 Santiago, Chile
[b] Center for the Development of Nanoscience and Nanotechnology (CEDENNA), Avda. Ecuador 3493, 917-0124 Santiago, Chile

ARTICLE INFO

Article history:
Received 20 July 2011
Received in revised form
1 September 2011
Available online 12 September 2011

Keywords:
Nanomagnetism
Asymmetric ring
Magnetic property

ABSTRACT

During the last decade several methods to control the vortex chirality in nanodots have been proposed. One of them, the introduction of asymmetry in the geometry of the dots, originates interesting effects on the magnetic behavior of the particle. However, asymmetry in core-free structures is also interesting to investigate because of the reproducibility of their magnetic properties. In this work we report systematic changes in the coercivity and remanence in asymmetric nanorings. The angular dependence is also addressed. For specific geometries and magnetic field direction newly reversal modes appear associated with important changes in the coercivity and remanence of the rings.

1. Introduction

The interest in magnetic nanostructures has drastically increased in the last years, mainly due to the great progress in experimental techniques, which allows access to the nanometer length scales. Besides the basic scientific interest in the magnetic properties of these systems, there is an evidence that they might be used in the production of magnetic devices, such as high-density storage media [1], high-speed magnetic random access memories [2,3], and magnetic sensors and logic devices [4].

Lithographed magnetic nanostructures offer interesting possibilities for tailoring their properties through the suitable choice of their geometry [5]. Among the available geometries, ferromagnetic nanorings attracted strong attention. Rings are characterized by its external and internal radii and its height. Then, and as compared with dots, they offer one more geometric parameter which can be distinctly varied. Also they display a very stable flux-closure magnetization pattern, where the magnetization follows the ring edges either in a clockwise or counterclockwise direction [6]. Besides, this core-free magnetic configuration leads to almost reproducible switching fields, guaranteeing reproducibility in read-write processes [7]. In symmetric rings the reversal from the onion state—characterized by the presence of two opposite head to head walls [8,9]—to the flux closure magnetization pattern is driven by the nucleation and propagation of a domain wall. Then, for an isolated ring the orientation of the initial onion state determines the flux closure magnetization circulation direction [10,11] or chirality. In the case of dots, the chirality is undetermined, and several methods have been used to achieve its control. The use of magnetic pulses [12] or magnetic field gradient [13] have been explored, but also the geometry has been considered by including asymmetries [14,15] that lead to control the chirality.

Recent studies have used asymmetric rings to achieve control over the flux closure magnetization chirality [16–18]. In particular, Giesen et al. [19] argue that the flux closure magnetization circulation direction becomes determined by the asymmetry, which suppresses the domain-wall propagation as reversal process and thereby generates a control over the flux closure magnetization circulation. Following these ideas, in this paper micromagnetic simulations have been used to systematically investigate the magnetic properties and reversal process of non-interacting asymmetric nanorings as a function of their geometry. We focus on the behavior of the coercive field and the remanence magnetization where strong effects have been found as a function of the geometry and the angle at which the field is applied.

2. Micromagnetic simulation

Analytical calculations can only be used in systems of simple shape and making use of simplifying assumptions [20], because the dipolar contribution is of long range. Thus, rings are particularly suited for such analytical calculations [21,22]. However, for systems having a complex geometry, like asymmetric rings, numerical simulations are required.

We performed micromagnetic simulations using the 3D OOMMF package [23]. Under this frame, the ferromagnetic system is divided into cubic cells with a uniform magnetization inside each cell. In order to obtain an adequate description of the

* Corresponding author at: Departamento de Física, Universidad de Santiago de Chile (USACH), Avda. Ecuador 3493, 917-0124 Santiago, Chile.
E-mail addresses: jescrigm@gmail.com, juan.escrig@usach.cl (J. Escrig).

0304-8853/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2011.09.001

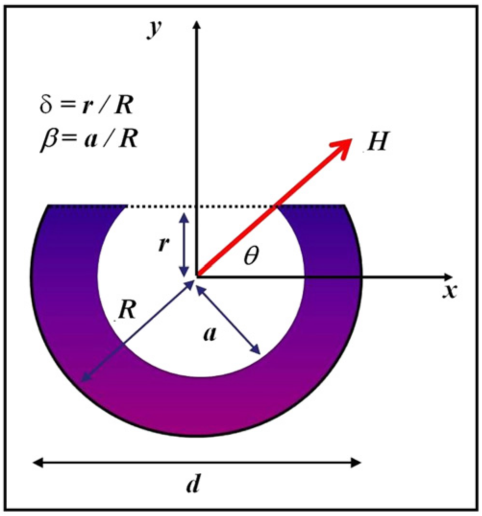

Fig. 1. (Color online) Geometry characterization of a nanoring. The dotted line illustrates the section that has been cut.

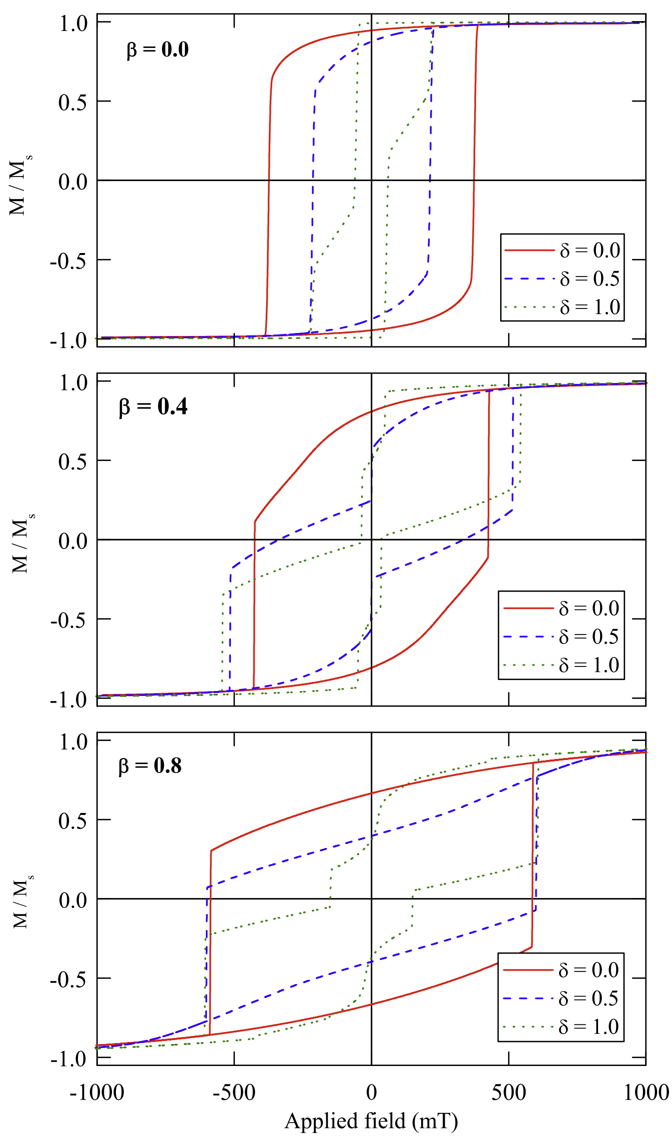

Fig. 2. (Color online) Hysteresis loops for an asymmetric ring as a function of δ for different values of β.

magnetization details, the size of the mesh has to be smaller than the exchange length of the material, defined by $l_{ex} = \sqrt{2A/\mu_0 M_s^2}$.

As stated above, we focus on rings defined by their height L, external radius R and aspect ratio $\beta = a/R$, with internal radius a. Thus a full dot is represented by $\beta = 0.0$ while very narrow rings are characterized by β close to 1.0. We introduce asymmetries in these rings by cutting specific sections characterized by the parameter $\delta = r/R$, as illustrated in Fig. 1. A symmetric ring is characterized by $\delta = 1.0$, while a semi-circular ring is represented by $\delta =$ 0.0.

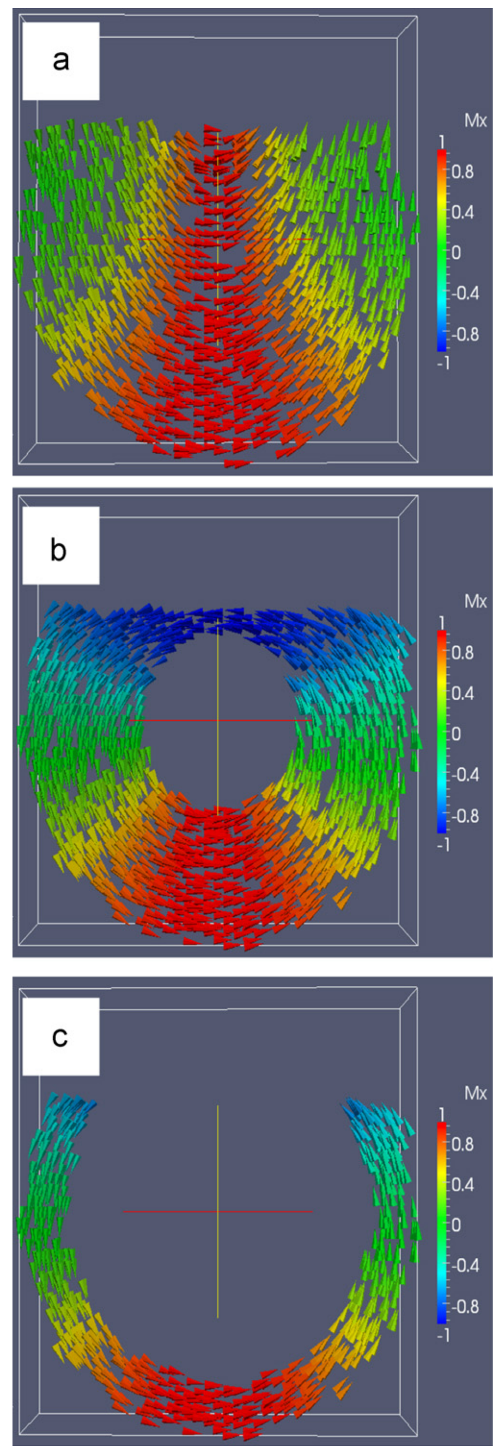

Fig. 3. (Color online) Snapshots of the stable magnetization state corresponding to H = 190 mT for $\delta = 0.5$ and $\beta = 0.0$ (a), $\beta = 0.4$ (b), and $\beta = 0.8$ (c).