Preparation and characterization of antidot complement of square artificial spin ice

I.R.B. Ribeiro,[1,2] R.C. Silva,[3] S.O. Ferreira,[1] W.A. Moura-Melo,[1] A.R. Pereira[1] and C.I.L. de Araujo[1]

[1]Universidade Federal de Viçosa, Dept. of Physics, 36570-900, Minas Gerais, Viçosa, Brazil
[2] Instituto Federal de Educação, Ciência e Tecnologia do Espírito Santo, Campus de Alegre, 29500-000, Espírito Santo, Alegre, Brazil
3 Universidade Federal do Espírito Santo, Dept. of Physics, 29932-540, Espírito Santo, São Mateus, Brazil

irbribeiro@yahoo.com.br

Abstract

Nanomagnetism has been intensively investigated due its unusual properties and promise for possible applications ranging broadly from information storage using topological objects (vortices and skyrmions) [1-2] as well as many biological and medical applications such as magnetic separation, hyperthermia treatment, magnetic resonance contrast enhancement and drug delivery [3]. Recently, significant interest has emerged in fabricated systems that mimic the behavior of geometrically frustrated materials. Wang *et al.* [4] have fabricated artificial spin ice (ASI): elongated single-domain ferromagnetic nanoislands organized in regular square lattice.

Based in this geometry we fabricated a lattice of elongated holes (antidots), with the aspect ratio of 2:1 (length: width), arranged in a nickel film mimicking the geometry of the ASI system, referred to as antidot-ASI [5]. To prepare these structures on silicon (100) substrate, first was deposited a polymethyl methacrylate (PMMA) layer of 250 nm by spin coating. Then, the silicon with PMMA was dried in hotplate. Subsequently, the desired pattern was defined by e-beam lithography. After e-beam exposure and developing, the structures were transferred into the Thermionics E-Beam evaporation system where a homogeneous 25 nm nickel film was evaporated over an 8 nm titanium seed layer. The nickel was capped with 3 nm of Au to prevent oxidation of the magnetic material. The procedure was completed by lift-off process in acetone ultrasonic bath. Atomic force microscopy (AFM) image of the final sample structure are shown in Figure1.

In the hysteresis loop, obtained by Vibrating Sample Magnetometry (VSM), was made in two distinct configurations with external magnetic field applied along 0º and 45º in relation to a horizontal side. The measurements show the square-like shape of the hysteresis loop and an increase of the coercive field, when external field is applied on the sample diagonal 45º instead of aside the square pattern 0º. From micromagnetic simulations performed with computational codes provided by the Object Oriented MicroMagnetic Framework (OOMMF) [6] we found good agreement between experimental and computational hysteresis loop. So we could investigate the spin configuration in different stages of the hysteresis curve. Furthermore, these simulations revealed the existence of an array of crystal vortices (Figure 2a) with random polarization and chirality (Figure 2b).

In order to investigate the topological crystal vortex magnetization by magnetoresistive measurements were realized, with external magnetic field applied in configuration longitudinal (Figure 3a), transversal and perpendicular to the 8.1 mA applied current. The main magnetoresistive peak observed is attributed to the randomic orientation of vortex crystal polarization and chirality at zero field, causing increase in resistance due to higher density of scattering and spin mixing. The saturation of magnetization in longitudinal and transversal configuration or vortex core orientation with external field out of plane (perpendicular), providing low resistive path and consequently low resistance. It is worth mentioning that, the anisotropic behavior expected for nickel thin films can be observed just in the zoom around the curve peak (Figure 3b).

The crystal vortices pattern observed in the electrically connected propose antidote-ASI system suggest it as promising for further investigations and applications in future spintronics.

References

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Figures

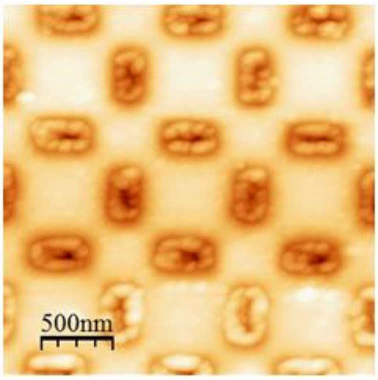

Figure 1. AFM image of the antidot lattice sample that are holes and their array mimics the artificial spin ice geometry.

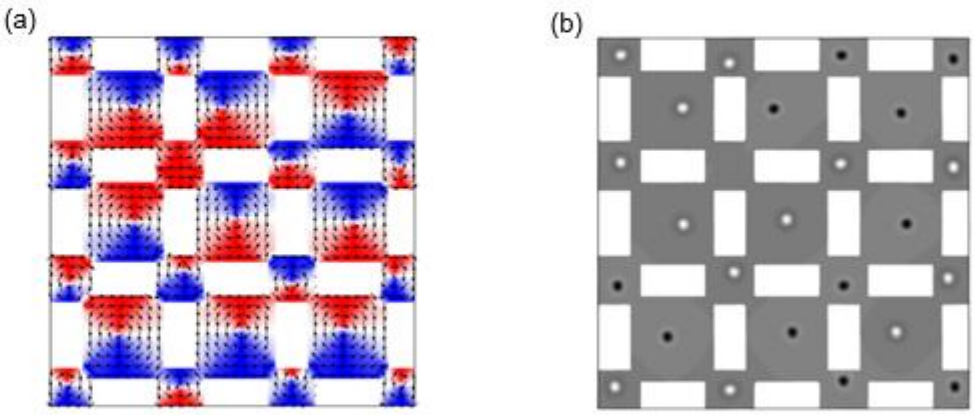

Figure 2. We show the results from simulation in OOMMF of 9 cells revealing the vortex-crystal chiralities in (a) and core polarizations represented by black and white central spots in (b).

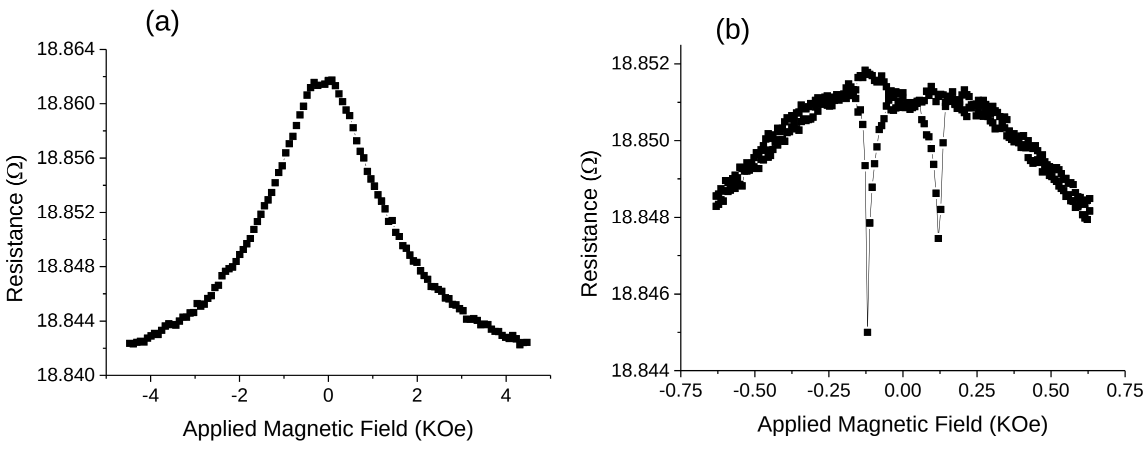

Figure 3. The magnetoresistive measurement with external magnetic field applied in configuration longitudinal (a) and zoom of peak (b).