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Antidot shape dependence of switching mechanism in permalloy samples

Hakan Yetiş*, Haluk Denizli

Abant Izzet Baysal University, Physics Department, Gölköy Campus, 14280 Bolu, Turkey

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ABSTRACT

We study antidot shape dependence of the switching magnetization for various permalloy samples with square and triangular arrays of nanometer scale antidots. The remnant magnetization, squareness ratio, and coercive fields of the samples are extracted from the hysteresis loops which are obtained by solving the Landau-Lifshitz-Gilbert (LLG) equation numerically. We find several different magnetic spin configurations which reveal the existence of superdomain wall structures. Our results are discussed in terms of the local shape anisotropy, array geometry, and symmetry properties in order to explain the formation of inhomogeneous domain structures.

1. Introduction

Control and manipulation of spin wave excitation and propagation have crucial importance in order to achieve faster information transferring and processing in magnonic devices [1]. The implication of regular arrays of nanometer scale antidots acting as pinning sites in a ferromagnetic material is of particular interest due to its underlying role on the realization of magnonic devices [2–6]. Antidot arrays introduced into a continuous magnetic thin film are capable to modify the magnetic properties such as formation of novel domain configurations [7–9], additional contribution to anisotropy [10–13], and magnetization reversal process [4,6,14]. Dynamic response in submicron patterned magnetic thin films is also fascinating due to the remarkable change in the spin wave spectra [1,15–18]. A well-chosen configuration of the nano size antidots can open the possibility of designing films with desired properties [19,20].

Antidots are capable to induce a spatially varying shape anisotropy and modify the local magnetization distribution which causes an increase in the coercive field and formation of the superdomain (SD) structures separated by super domain walls (SDWs) at remnant state [8,9]. The magnetic spin states confined in a region between antidots are of crucial importance for some practical applications in which the common average magnetic spin direction is used as a magnetic bit for the information storage [3,9]. The nano size antidots can also serve as nanometer scale waveguides in terms of the spin wave filtering [3].

This work is an extended version of our previous work in which the circular shape antidots are studied [21]. Permalloy samples with different antidot shapes have been studied by long-time simulations to search the geometry and shape dependence of coercivity in permalloy films by means of the hysteresis loops (*M*–*H* curves), magnetic spin configurations, and demagnetizing energy (E_d) curves. Our results indicate that the choice of antidot parameters in a finite sized ferromagnetic Py film strongly affects the overall magnetic reversal process, distinguished by different domain structures. We find significant increase in the coercivity of the sample having TAs of the tilted square or diamond shaped antidots. The important results of the present work are interpreted in terms of the local antidot shape anisotropy and the formation of SDs and SDWs in a finite size sample. The outline of the paper is as follows. In Section 2, we give an overview of the model and the simulation technique and its parameters. The main results of the study are discussed in Section 3. The paper concludes with a brief summary of the main findings in Section 4.

2. Model

Due to available computing power, we use 2D solution (mmSolve2D solver of OOMMF) of the Landau-Lifshitz-Gilbert (LLG) equation for permalloy samples having different numbers of various shaped antidots of square and triangular arrays as shown in Fig. 1 in the present study. Average computing time for a single set of simulations takes 18 days. Total computing time for 28 different simulations is about 504 days with 4xAMD Opteron 2.5 GHz computer. The mmSolve2D is capable of solving problems defined on a two-dimensional grid of square cells with three-dimensional

* Corresponding author.
E-mail address: hknyetis@gmail.com (H. Yetiş).

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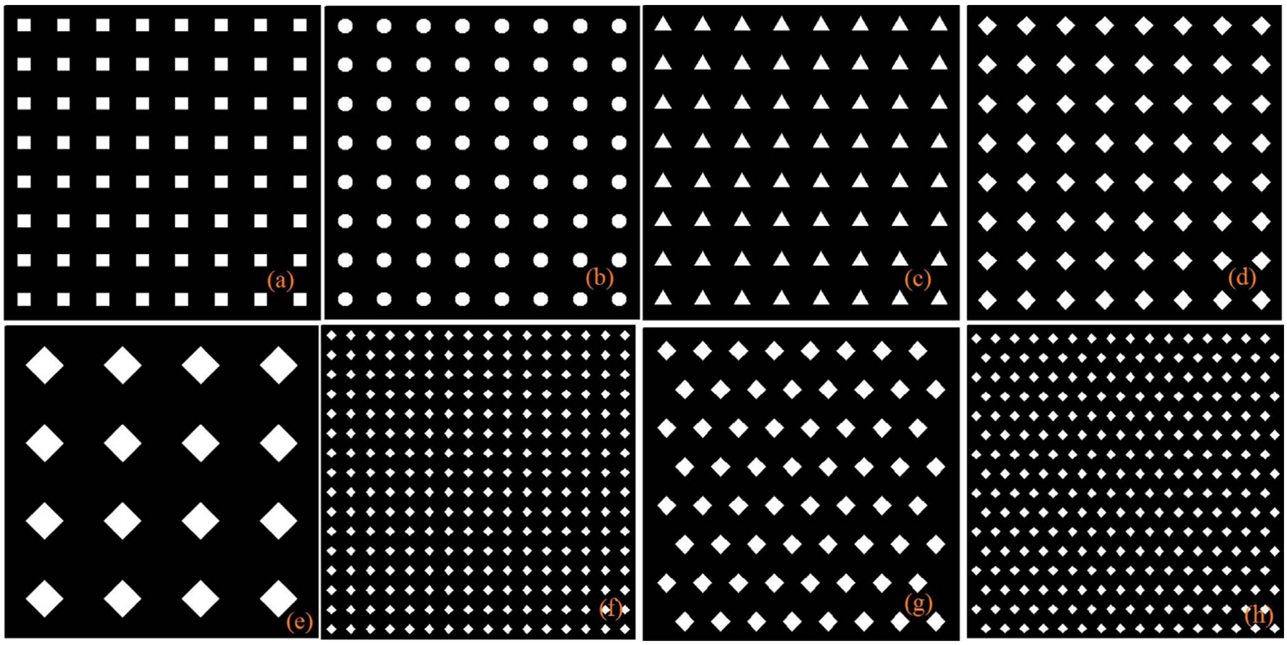

Fig. 1. presents some examples of patterned Py samples used in our 2D simulations. Fig. 1**(a)** to 1**(d)** show 8 × 8 square arrays (SAs) of square, circle, up-triangle, and diamond shaped antidots, respectively. 4 × 4 and 16 × 16 SAs in Fig. 1**(e)** and 1**(f)** and 4 × 4 and 16 × 16 triangular arrays (TAs) in Fig. 1**(g)** and 1**(h)** of diamond shaped antidots are presented. The white circles denote the non-magnetic (NM) antidots and black regions represent the continuous permalloy magnetic material (PMM). The sample sizes are $d_a = 200$ nm, 100 nm, and 50 nm in descending order. The 2D simulations are performed on the square films with an area of $2.0 \times 2.0\ \mu m^2$ and thickness 20 nm.

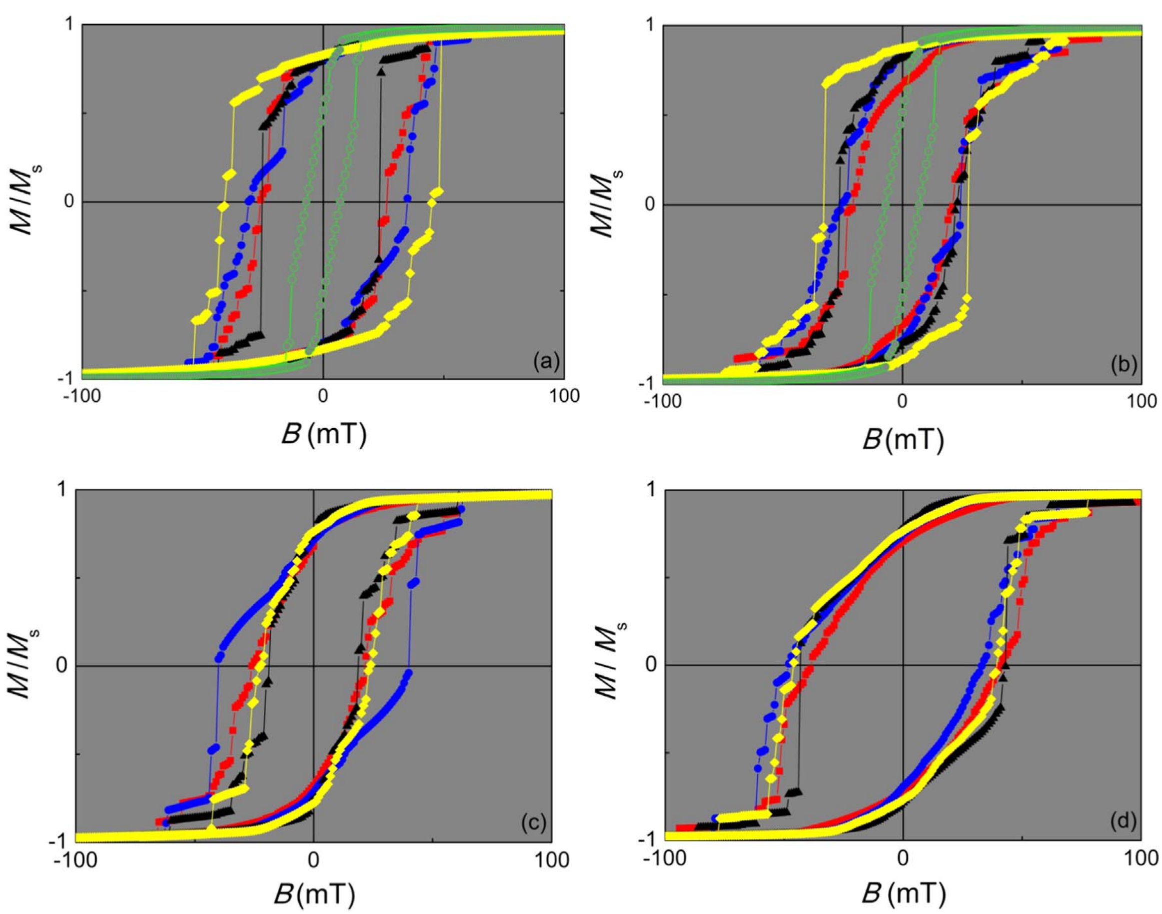

Fig. 2. The hysteresis loops are presented for the samples with **(a)** 8 × 8, **(b)** 16 × 16 TAs and **(c)** 8 × 8, **(d)** 16 × 16 SAs of different shaped antidots shown in Fig. 1(a) to (d). The M/M_s is the normalized magnetization value. M_r is the remnant magnetization value. M/M_s vs. B curves are plotted by colored lines with symbols which denote the related antidot shape.