

Field effect on domain wall trapping and domain wall motion in notch free NiFe asymmetric nanorings

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

2011 J. Phys.: Conf. Ser. 266 012085

(<http://iopscience.iop.org/1742-6596/266/1/012085>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 155.69.203.1

The article was downloaded on 19/04/2011 at 04:53

Please note that [terms and conditions apply](#).

Field effect on domain wall trapping and domain wall motion in notch free NiFe asymmetric nanorings

X.H. Wang, I. Purnama, S. Goolaup and W.S. Lew
*Physics and Applied Physics Division, School of Physical and Mathematical Sciences,
Nanyang Technological University, 21 Nanyang Link, Singapore 637371*

E-mail: wensiang@ntu.edu.sg

Abstract. We report on the simulation of domain wall trapping and field hysteresis effect on domain wall in notch free asymmetric ring structures. Our results reveal that a domain wall is trapped at the narrow arm of the asymmetric ring when a vortex state is formed. The chirality of the vortex is found to be dependent on the field history of the asymmetric nanoring. The domain wall behavior under the externally applied magnetic field is found to be related with the chirality of the vortex of the asymmetric ring.

1. Introduction

Domain walls and domain wall (DW) motions have attracted intense research interest due to their potential significance in spintronic applications, for example, data storage[1] and magnetic logic devices[2]. For optimum performance of these devices, understanding the details of DW formation and motion plays an essential role. A lot of research efforts have been dedicated to manipulating the DWs using magnetic fields[3] and/or spin-polarized current[4] originating from the spin-transfer torque[5]. In the conventional field switching devices, the reduction of device size down to nanoscale causes significant increase[6] in the switching field, thus causing the disadvantage of high energy consumption. As a result, finding a way to trap a domain wall and depin it with a small field is of significant importance. In most experiments examining the domain walls, a DW is trapped at an artificially fabricated constriction[7] in nanowires or nanostripes. The artificially fabricated geometric defects such as notches traps the domain wall at the expense[8] of large DW depin field or current. To investigate magnetic switching mechanisms, a configuration in which different magnetic states can easily be realized is required[9]. A possible configuration that fulfills these criteria is the ring structure. Elongated ring structure and asymmetric ring[10] which is a ring structure with the inner circle off-centered, were also used to investigate the domain wall behavior. Previously we have reported simulation work on the domain wall trapping behaviour in the asymmetric ring structure[10].

In this paper, we present a systematic investigation of the influence of the field history on the domain wall trapping behavior in an asymmetric ring structure as shown in Fig. 1. The dimensions are $D_o=1200$ nm, $D_i=600$ nm. l is the distance between the centres of the two circles. The motion of the trapped domain wall under an externally applied field is also studied via micromagnetic simulations.

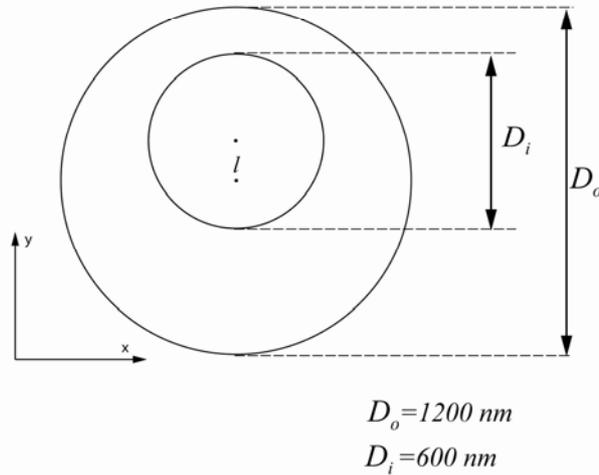


Fig.1 Schematic of the geometric model of the asymmetric ring.

2. Simulations

The magnetization configuration and switching properties were simulated using the Object Oriented MicroMagnetic Framework (OOMMF) simulation program[11]. In this simulation, the micromagnetic equilibrium equations were solved in a two dimensional square mesh with a cell size of 4 nm and the spins are free to rotate in three dimensions. The field was ramped from -1000 Oe to +1000 Oe in 200 steps. Other parameters used for the permalloy were crystalline anisotropy constant $K_1 = 0$, saturation magnetization $M_s = 8.6 \times 10^5 \text{ A}\cdot\text{m}^{-1}$, exchange stiffness $A = 1.3 \times 10^{-11} \text{ J}\cdot\text{m}^{-1}$ and the damping coefficient $\alpha = 0.5$. We assumed that the intrinsic uniaxial anisotropy of the bulk NiFe film is negligible when compared with the shape-induced anisotropy of the rings.

3. Results and discussions

3.1. Effect of field history on chirality control

In order to study the effect of the field history of the asymmetric magnetic ring on the switching processes and mechanisms, the hysteresis behavior of a magnetic asymmetric ring was simulated with the magnetic field applied both in x axis and y axis. Repeated simulations using the same parameters have been carried to confirm the reproducibility of the results Fig.2 shows the simulated switching process of the 8-nm-thick Ni80Fe20 asymmetric nanorings with the field applied in y axis. When a negative field of 1000 Oe is applied, the magnetization of the asymmetric ring adopts a negative saturation state. Reducing the field, an onion with two transverse domain walls nucleated at the narrow arm and wide arm of the asymmetric ring, forming an onion state with magnetization aligns along the -y direction. When the field is reversed, the domain wall at the wide arm begins to move towards the narrow arm, while the domain wall at the narrow arm stays as shown in process I in Fig.2.

However, the route is selected randomly. The domain wall either moves via the left arm or the right arm of the asymmetric ring. These two kinds of switching both result a domain wall trapping vortex state. However, the chirality of the domain wall trapping vortex states is not determined. Shown in Fig.2 are the two kinds of switching process. The captured remanence states of the two kinds of switching processes are anticlockwise and clockwise domain wall trapping vortex.

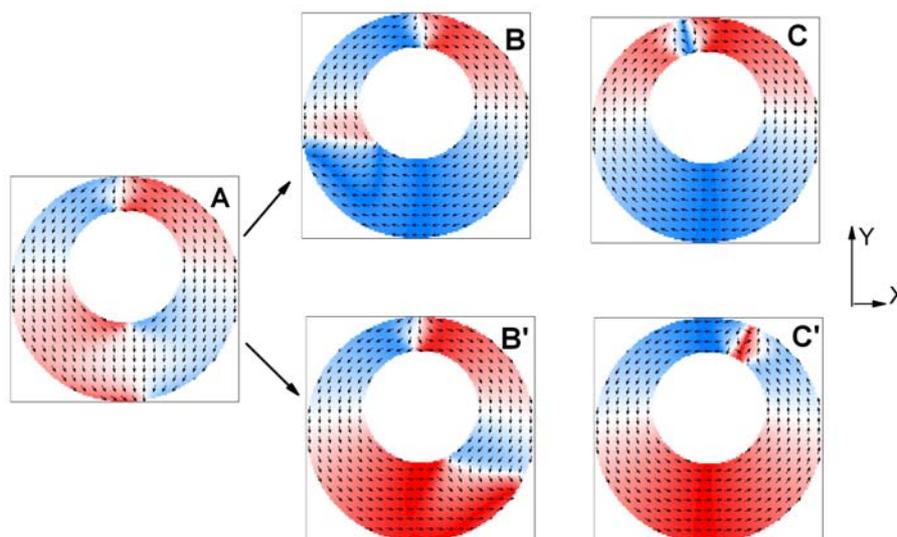


Fig.2 Two different switching process after saturating the magnetization along negative y axis: A-B-C, forming a clockwise domain wall trapping vortex; A-B'-C', forming an anticlockwise domain wall trapping vortex. State A is the negative onion after saturation; state B, B' are domain wall movements via left and right arm of the asymmetric ring; state C, C' are clockwise and anticlockwise domain wall trapping vortex.

When the negative field was applied along the x axis of the asymmetric ring and then reduces, the magnetization of the asymmetric ring forms a negative onion with two transverse domain walls nucleated at the asymmetric axis. Reversing the field, the two domain walls both start to move towards the narrower arm of the asymmetric ring and form a vortex state with clockwise direction with a 360 degree domain wall trapped at the narrow arm. Shown in Fig.3 is the corresponding switching process. The chirality of the domain wall trapping vortex is thus determined by the field history. When the asymmetric ring is at the right beginning saturated in negative direction, the vortex is clockwise and vice verse.

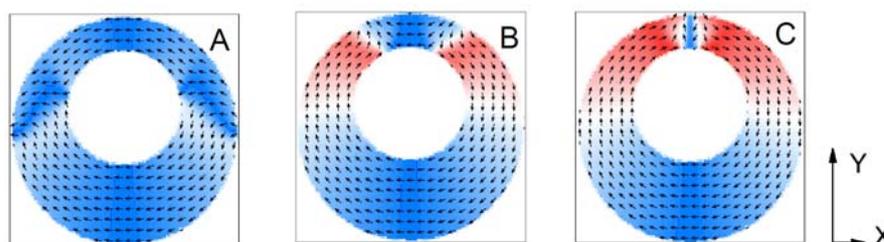


Fig. 3 Switching process after saturating the magnetization along negative x axis. State A is the onion state after saturation along x axis; state B is the domain wall movement via narrow arm

of the asymmetric ring; state C is the clockwise domain wall trapping vortex.

3.2. Chirality dependence of the field driven domain wall motion

After the domain wall trapping vortex state is obtained, we further study the field driven domain wall motion. By saturating the asymmetric ring along the $-y$ axis and then relaxed it, the domain wall trapping vortex states are formed. The chirality is by chance clockwise or anticlockwise. The field is to apply both in $-x$ and $+x$ direction. Considering the external fields direction and the two kinds of the chirality, there are four cases, which are: (i), clockwise vortex state with field applied in the $-x$ direction; (ii), clockwise vortex state with field applied in the $+x$ direction; (iii), anticlockwise vortex state with field applied in the $-x$ direction, and (iv) anticlockwise vortex state with field applied in the $+x$ direction. However, case (i) is same as case (iv), so as (ii) and (iii). As a result, only the domain wall motion with fields applied in $-x$ direction were studied, which are case (i) and (iii).

The simulation shows that the domain wall behaviors are markedly dependent on the chirality of the vortex. Starting from the domain wall trapping vortex as shown in Fig.4.(a), when the chirality is anti-clockwise, applying a magnetic field to $(-x)$ direction does not annihilate the trapped domain wall. Rather, another domain wall is nucleated from the wider part of the ring as can be seen as a switch at -160 Oe as shown in Fig. 4.(b). As the field is increased, the new wall moves to the left edge of the ring and stayed there. The trapped domain wall then annihilates at -620 Oe as shown in Fig.4.(c). The new domain wall does not annihilate even when the applied field is increased to a large value of 1000 Oe. Interestingly, when the direction of the vortex state is anti-clockwise, the field influences the trapped domain wall more significantly. A $-x$ field of 50 Oe breaks the trapped 360 degree domain wall in the anti-clockwise vortex (Fig.4(d)) into two transverse walls. The separated domain walls move apart quickly and annihilate, forming the a saturation magnetic state with the magnetization aligns to $-x$ which is shown in Fig.4(e).

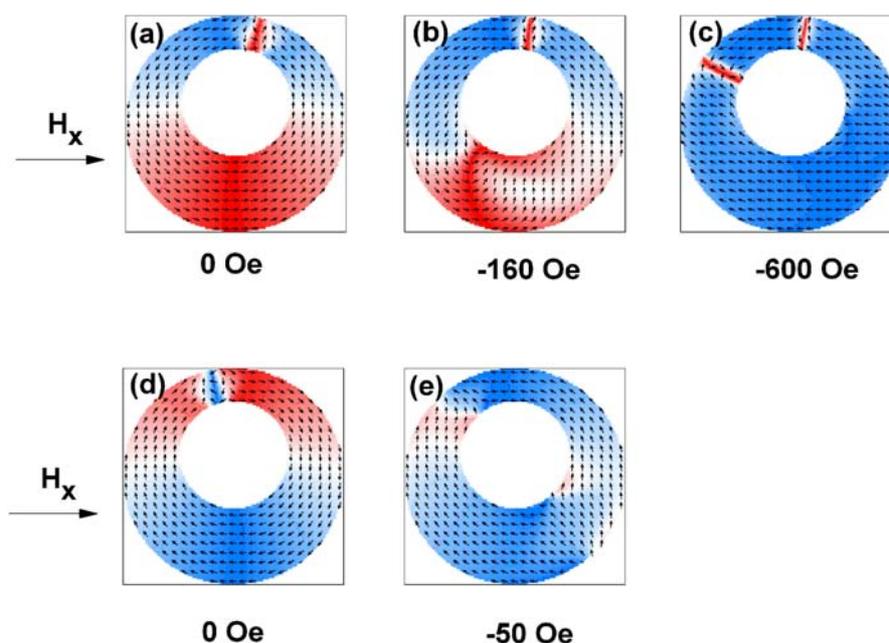


Fig.4 Simulated domain wall motion with different chirality in a 10-nm-thick NiFe asymmetric ring.(a) anticlockwise vortex with a 360 degree domain wall trapped at the

narrow arm; (b) nucleation of a second domain wall at the wide arm with a field of -160 Oe applied in the x axis; (c) two domain walls under a large field of -600 Oe; (d) clockwise vortex with a 360 degree domain wall trapped at narrow arm; (e) negative 'onion' in a small field of -50 Oe in the x axis.

4. conclusions

We have studied the magnetic field orientation effects on the domain walls behavior in asymmetric nanoring using micromagnetic simulation. At certain thickness a 360 degree domain wall is trapped at the narrow arm of the vortex state at remanence. The chirality of the vortex is found to be dependent on the field history of the asymmetric nanoring. The magnetic field orientation effects on the domain walls behavior are also studied. The simulation results show that the domain wall behavior under the externally applied magnetic field is found to be related with the chirality of the vortex of the asymmetric ring.

5. acknowledgement

This work was supported in part by the ASTAR SERC grant (082 101 0015) and the NRF-CRP program (Multifunctional Spintronic Materials and Devices).

6. References

- [1] Parkin S. S. P., Hayashi M., Thomas L., 2008, *Science*, **320** 190-194.
- [2] Allwood D. A., Xiong G., Faulkner C. C., Atkinson D., Petit D., Cowburn R. P. 2005, *Science*, **309** 1688, .
- [3] Beach G. S. D., Nistor C., Knutson C., Tsoi M. & Erskine J. L., 2005, *Nature Mater.*, **4** 741-744.
- [4] Krause S., Berbil-Bautista L., Herzog G., Bode M, Wiesendanger R., 2007 *Science*, **317** 1538-1540.
- [5] San Emeterio Alvarez L., Wang K.-Y., Lepadatu S., Landi S., Bending S. J., Marrows C. H. 2010, *Phys. Rev. Lett.*, **104** 137205.
- [6] García N., Saveliev I. G., Zhao Y. -W. and Zlatkine A., 2000, *J. Magn. Magn. Mater.*, **214** 7-12.
- [7] Lepadatu S., Wessely O., Vanhaverbeke A., Allenspach R., Potenza A., Marchetto H., Charlton T. R., Langridge S., Dhési S. S., Marrows C. H., *Phys. Rev. B.*, **81** 060402.
- [8] McMillen M., McQuaid R. G. P., Haire S. C., McLaughlin C. D., Chang L. W., Schilling A., Gregg J. M., 2010, *Appl. Phys. Lett.*, **96** 042904.
- [9] Singh D. K., Krotkov R., and Tuominen M.T., 2009, *Phys. Rev. B*, **79** 184409.
- [10] Wang X. H., Peng W. K., Lew W.S, 2009, *J. Appl. Phys.*, **106** 043905-4.
- [11] "Availabe at <http://math.nist.gov/oommf>."