Journal of Magnetics 11(2), 74-76 (2006)

Dynamics of Transverse Magnetic Domain Walls in Rectangular-shape Thin-film Nanowires Studied by Micromagnetic Simulations

Jun-Young Lee, Sangkook Choi, and Sang-Koog Kim*

Research Center for Spin Dynamics & Spin-Wave Devices (ReC-SDSW) and Nanospintronics Laboratory,
School of Materials Science and Engineering, Seoul National University, Seoul 151-744, Korea

(Received 5 June 2006)

Dynamic behaviors of transverse domain walls (TDWs) in rectangular shaped thin-film magnetic nanowires with different widths under applied magnetic fields less than the Walker field were studied by micromagnetic simulations. It was found that the velocity of stable TDWs in the viscous region increases from 147 to 419 m/s and their mass decreases from 6.24×10^{-23} to 2.70×10^{-23} kg with increasing strength of the applied magnetic field ranging from 5 to 20 Oe for the nanowire with a dimension of 10 nm in thickness and 5 μm in length, and 50 nm in width. With increasing the width of nanowires from 50 to 125 nm at a specific field strength of 5 Oe, the TDW's velocity also increases from 147 to 246 m/s and its mass decreases from 6.24×10^{-23} to 5.91×10^{-23} kg.

Key words : domain wall velocity, domain wall mass, micromagnetic simulations

1. Introduction

Dynamic behaviors of magnetic domain walls in variously shaped magnetic thin-film nanowires have attracted much attention [1] because of their applications to magnetic information storage [2, 3] and logic devices [4]. From a technological point of view, the speed of domain wall motions is crucially important to the determination of the speed of information writing or recording in storage devices, as well as the speed of logical operations in a new paradigm of magnetic logic devices.

It is thus necessary to fundamentally understand the dynamic motion of domain walls in magnetic thin-film nanowires with different dimensions, particularly with various widths, w, under given magnetic fields, H. In the present work, using micromagnetic simulations we studied the dynamics of domain wall motions, specifically, of a type of transverse domain walls (TDWs). The dependences of the velocity, v, and effective mass, m, of TDWs on both H and w in a steady state of their motion are investigated by micromagnetic simulations.

2. Simulations

Micromagnetic simulations were carried out on rectangular shaped thin-film nanowires with different values of w under various H's. The dimensions of the model nanowires made of Permalloy (Py) are the same thickness of 10 nm and length of 5 μm, but with different widths, such as w = 50, 75, 100, and 125 nm. The material parameters corresponding to Py are as follows: a saturation magnetization of $M_S = 8.6\times10^5$ A/m, an exchange constant of $A = 1.3\times10^{-11}$ J/m, an anisotropy constant of $K = 0$ J/m^3. The dimension of a unit cell is 5 nm × 5 nm × 10 nm and the Gilbert damping constant is $\alpha = 0.01$. The dynamics and precessional motions of the magnetizations of individual cells are described by the Landau-Lifshitz Gilbert (LLG) equation and simulated using the OOMMF code [5].

3. Results and Discussion

In order to form a well defined TDW in a model nanowire system, a shape of head-to-head domain wall is intentionally made at the center of the long axis of the nanowires and then relaxed toward its equilibrium state in a given geometry under $H = 0$ Oe, as shown in Fig. 1 [6]. The colors of the image display the in-plane components

---

*Corresponding author: Tel: +82-2-880-5854,
Fax: +82-2-885-1457, e-mail: sangkoog@snu.ac.kr

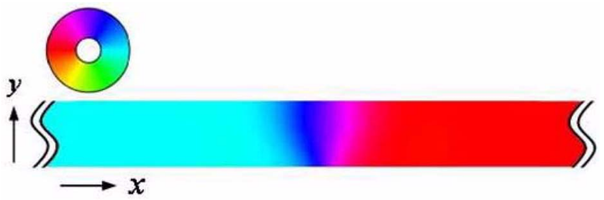

Fig. 1. (Online color) An equilibrium state in a rectangular shaped thin-film nanowire with a dimension of 10 nm in thickness and 5 μm in length, and 50 nm in width, which includes a well-formed transverse domain wall placed at the center of the long axis of the wire under zero magnetic field. The colors indicate the in-plane orientation of local magnetizations as noted by the color wheel. The image shows only a part of the entire length of the wire.

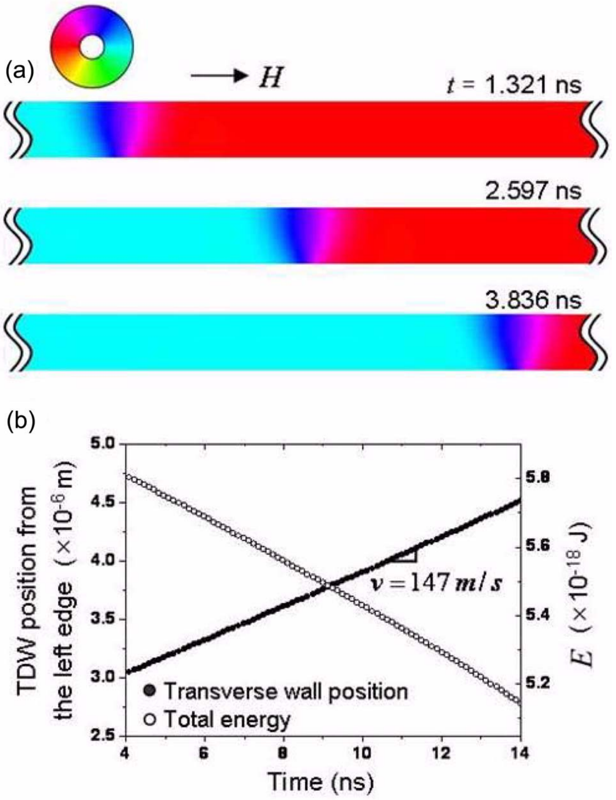

Fig. 2. (Online color) Temporal evolution of the TDW from the left to right side under a magnetic field of H=5 Oe. (a) Color images taken at the indicated times for the spatial distribution of the local M_x/M_s. (b) Plot of the position of the TDW and the total energy of the magnetization configurations during the TDW motion.

of local magnetizations whose orientations are indicated by the directions of the color wheel. The initial magnetization configuration wherein a well-formed TDW is contained is then perturbed using static magnetic fields applied along the +x direction with its different strengths of $H = 3$, 8, 10, 13, 15, 18, 20, and 21 Oe. Figure 2(a) shows the temporal evolution of the motion of the TDW under the given $H = 5$ Oe for $w = 50$ nm. The TDW under the given uniform field less than the Walker field, H_w, [7] moves in a steady state toward the +x direction, i.e., the right side of the long axis of the nanowire. To elucidate the dynamic motion of the TDW, its position and the total energy, E, of the individual magnetization configurations within the wire during the TDW motion are also plotted as a function of time, t, as seen in Fig. 2(b). The TDW in the given geometry moves with a constant velocity of $v = 147$ m/s under the given H less than H_w. The value of E also linearly decreases from 5.82×10^{-18} to 5.15×10^{-18} J. The value of m is then estimated to be 6.24×10^{-23} kg by the relation of $E = E_0 + (1/2)m\ v^2$, where E_0 is the domain wall energy at the initial state and E at the final state in a constant velocity region.

To examine the dependences of the values of v and m on both H and w, additional micromagnetic simulations were performed on the same geometry with the different fields of $H = 3$, 8, 10, 13, 15, 18, 20, and 21 Oe for a constant value of $w = 50$ nm, and with the different widths of $w = 50$, 75, 100, and 125 nm for a fixed value of $H = 5$ Oe. The total energy difference, ΔE, between the initial and final states in the constant velocity region, and the values of v and m for the TDW motion are plotted versus H/H_w for $w = 50$ nm and versus w for $H = 5$ Oe, as

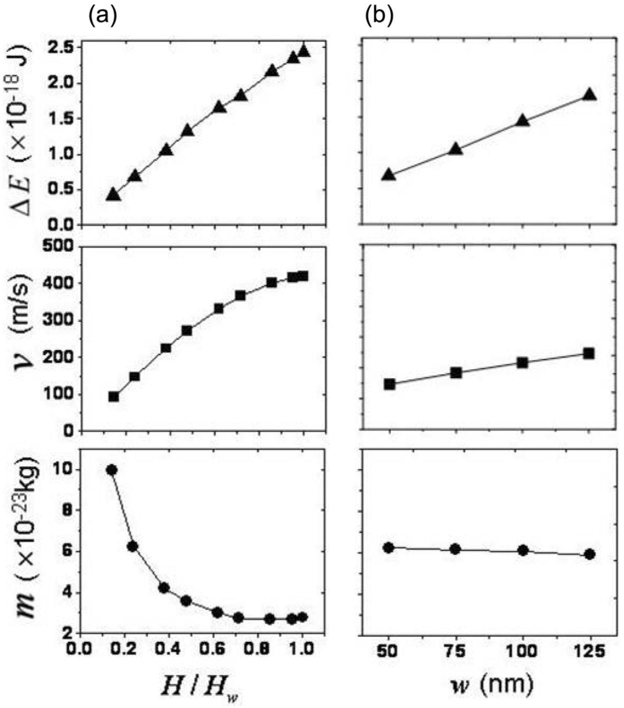

Fig. 3. The velocity and mass of TDWs, and the energy difference in the region of their steady motions versus both H/H_w and w. The energy difference is defined in the text.

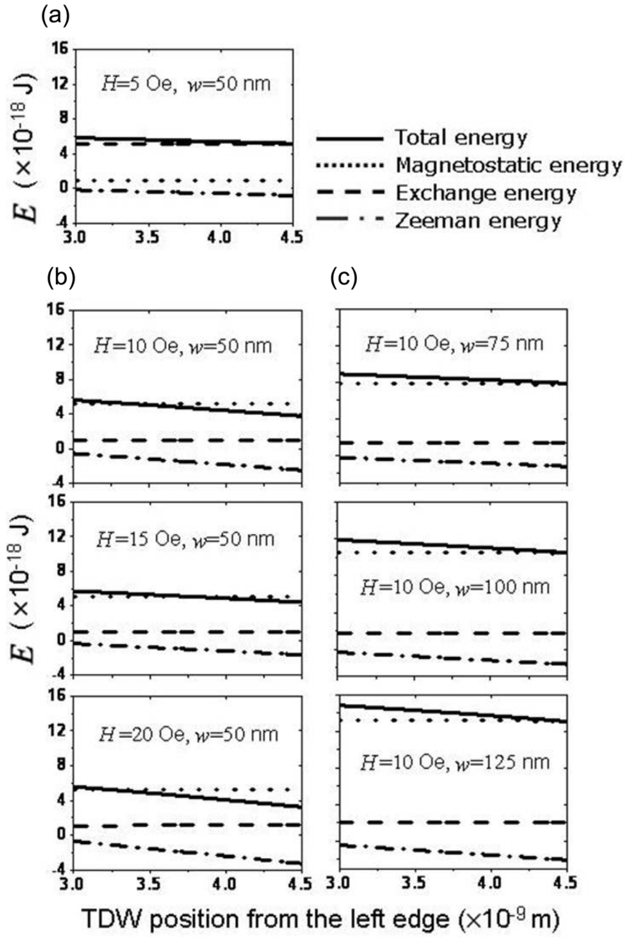

Fig. 4. Dependences of the total, exchange, Zeeman, and magnetostatic energies versus the TDW position for $H = 5$ Oe and $w = 50$ nm in (a), and $H = 10$, 15, 20 Oe and $w = 50$ nm in (b), and $w = 75$, 100, 125 nm and $H = 5$ Oe in (c).

shown in Fig. 3. As the value of H/H_w increases, ΔE increases linearly from 6.76×10^{-19} to 2.44×10^{-18} J. The increase of ΔE is due predominantly to the increase of the Zeeman energy term during the TDW motion. Simultaneously, the value of v increases from 147 to 419 m/s and the value of m decreases from 6.24×10^{-23} to 2.70×10^{-23} kg with increasing H/H_w. The value of ΔE increases linearly with increasing w from 6.76×10^{-19} J at $w = 50$ nm to 1.80×10^{-18} J at $w = 125$ nm, due to the contribution of the Zeeman energy. Note that the contributions of the exchange and magnetostatic energy terms to the total energy are negligible during the TDW motion, as shown in Fig. 4. The magnitude of v increases from 147 to 246 m/s and m decreases from 6.24×10^{-23} to 5.91×10^{-23} kg, with increasing width from 50 to 125 nm for $H = 5$ Oe. However, the variations of those parameters with w are much smaller than those with H.

The underlying physics of the decrease of m with increasing H/H_w can be understood as follows. The total energy difference during the motion of domain walls is affected mainly by the Zeeman energy contribution because the exchange and magnetostatic interaction contributions are not much varied during the domain wall motions. Hence, ΔE is inversely proportional to H in the viscous region, and the value of v has a linear dependence on H, such as $v = (\gamma\Delta/\alpha)H$ in the viscous regions [4], where Δ is the wall-width parameter, and γ is the gyromagnetic ratio. Consequently, m is inversely proportional to H, as $m \approx 2[\Delta M \cdot H/\{(\gamma\Delta/\alpha)H\}^2]1/H$, which is in a good agreement with the results of the present micromagnetic simulations.

4. Conclusion

The dynamic motion, and the velocity and mass of TDWs in rectangular shaped Permalloy thin-film nanowires were investigated using micromagnetic simulations. From the modeling study it is found that the velocity of TDWs in the viscous region increases from 147 to 419 m/s and their mass decreases from 6.24×10^{-23} to 2.70×10^{-23} kg, with increasing magnetic field from 5 to 20 Oe for the thickness of 10 nm and length of 5 μm, and width of 50 nm. Also, the velocity increases from 147 to 246 m/s and the mass decreases from 6.24×10^{-23} to 5.91×10^{-23} Kg with increasing width from 50 to 125 nm for $H = 5$ Oe.

Acknowledgements

This work was supported by the Korean Ministry of Science and Technology through the Creative Research Initiative Program.

References

[1] W. Y. Lee, K. H. Shin, H. J. Kim, and J. A. C. Bland, J. of Magnetics **6**(2), 47 (2001).
[2] Tsoi, M., Fontana, R. E. and Parkin, S. S. P., Appl. Phys. Lett. **83**, 2617 (2003).
[3] Grollier, F. J. Grollier, P. Boulenc, V. Cros, A. Hamziæ, A. Vaurés, A. Fert, and G. Faini, Appl. Phys. Lett. **83**, 509 (2003).
[4] D. A. Allwood, G. Xiong, C. C. Faulkner, D. Atkinson, D. Petit, and R. P. Cowbourn. Science **309**, 1688 (2005).
[5] http:// math.nist.gov/oommf/.
[6] Nakatani, Y., Hayashi, N., Ono, T. and Miyajima, H. IEEE Trans. Magn. **37**, 2129 (2001).
[7] A. Thiaville, J. M. Garcia, and J. Miltat, J. Magn. Magn. Mater. **242-245**, 1061 (2002).