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Suppression of Magnetization Ringing After Domain Wall Collision Studied by Micromagnetic Simulation

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Magnetization ringing following domain wall collision on a ferromagnetic nanowire has been investigated by micromagnetic simulation. Suppressed magnetization ringing is observed with the introduction of a small ribbon to the nanowire. Magnetization ringing has been analyzed in a frequency space by a fast Fourier transform. With the introduction of a small ribbon and/or taping of the wire, the amplitude of ringing is reduced with a shifted frequency peak.

Keywords : domain wall collision, magnetization ringing, magnetization switching

1. Introduction

The understanding of magnetic domain wall (DW) dynamics in patterned ferromagnetic wire is important for future spintronics applications and magnetic memory [1]. Similarly to a magnetic racetrack memory device [2], the magnetic bit memory is stored by using DW dynamics, which is eventually involved in DW collision in the writing and erasing mechanism. To achieve an ultrahigh density magnetic recording or magnetic device, a better understanding of the DW collision process is required. In particular, controlling the amplitude and frequency of magnetization ringing after DW collision is of utmost importance, since the amplitude and frequency of magnetization ringing place an ultimate limit on the switching and operation speed of magnetic devices. Magnetization ringing behavior has been extensively studied both numerically and experimentally. It has been reported that magnetization ringing can be suppressed by tailoring the length of the applied field pulse [3]. An experimental observation of magnetization ringing behavior has been carried out by the time-resolved Kerr effect [4]. Recently, the incoherent magnetization dynamics occurring after DW collision in a rectangular pattern has been numerically studied [5]. However, a detailed study that addresses the suppression of magnetization ringing after a DW collision in a ferromagnetic nanowire has not been carried out.

In this work, we investigate the magnetization ringing behavior after DW collision in a ferromagnetic nanowire using the micromagnetic simulation. Two DWs are generated and driven to collide at the center with different applied fields. We carried out the micromagnetic simulation for three different shapes of wires. We then analyzed subsequent magnetization ringing after collision for the three types of wires, revealing that suppression of magnetization ringing is achieved by introducing a small ribbon at the position where DWs collide.

2. Micromagnetic Simulations

Micromagnetic simulation for magnetization ringing behavior after DW collision has been carried out using the public micromagnetic simulation software, OOMMF [6]. DW collision and subsequent magnetization ringing behavior have been analyzed for different shapes of ferromagnetic nanowires, i.e., pattern A, pattern B, and pattern C, as illustrated in Fig. 1. Pattern A is a simple ferromagnetic wire, pattern B is a wire with a small ribbon pattern attached at the center, and pattern C is a wire with a tapered width and a small ribbon pattern attached. The length of the ferromagnetic nanowire is set to be 3500 nm, while the width is 10 nm, and the thickness is 10 nm. A diamond-shaped launching pad with an aspect ratio of 1:3 at each end of the wire is used to easily trigger the DW formation at the end of the wire. The cellsize of micromagnetic simulation is set to be $10 \times 10 \times 10$ nm^3

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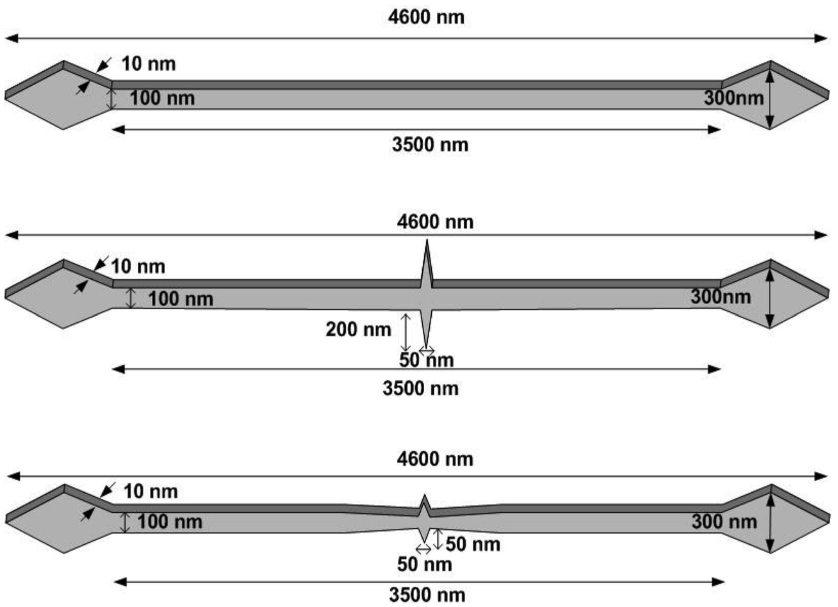


Fig. 1. Wire geometries for simple wire (pattern A), wire with ribbon (pattern B), and wire with ribbon and tapered width (pattern C).

and the damping coefficient α is 0.01. The Permalloy material parameters are used with a saturation magnetization M_s of 8×10^5 A/m, an exchange stiffness coefficient A of 13×10^{-12} J/m, and zero crystalline magnetic anisotropy.

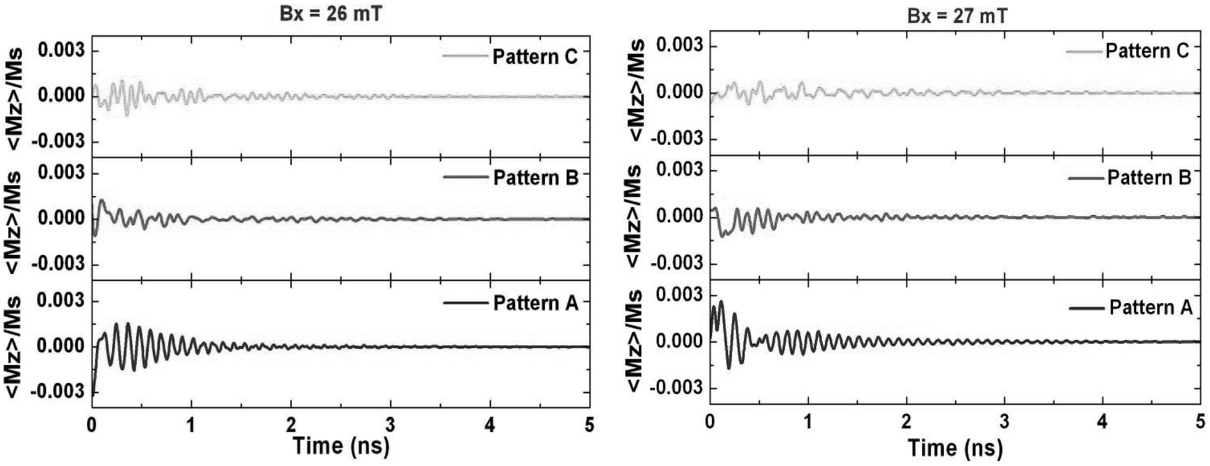
The DW dynamic along the nanowire is governed by the Landau-Lifshitz-Gilbert equation, as follows,

$$\frac{dm}{dt} = -\gamma\, m \times H_{eff} - \alpha m \times (m \times H_{eff}) \qquad (1)$$

where $\boldsymbol{m} = \boldsymbol{M}/M_s$ is a normalized magnetization, α is the damping coefficient, γ is the gyromagnetic ratio, M_s is the saturation magnetization, and $\boldsymbol{H}_{eff}$ is the effective field. Two DWs are generated at each end of the wires with a variation of external magnetic field strength. A constant external magnetic field is applied to generate two DWs in motion. The two DWs then propagate along the nanowire and collide with each other at the center of the wires. After the collision, the magnetization ringing appears with the annihilation of the two DWs.

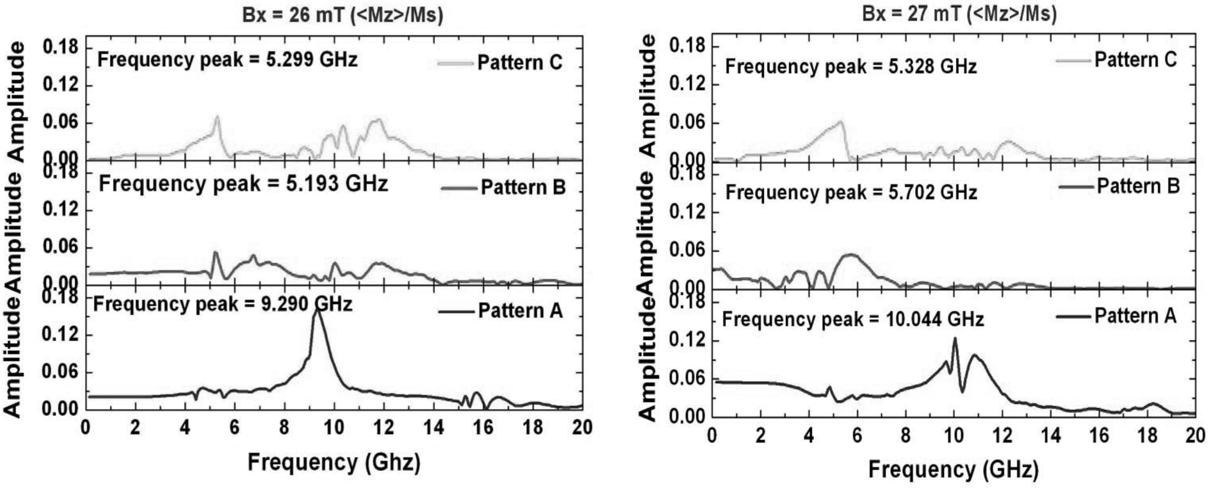
3. Results and Discussion

The evolution of the magnetization component M_z with respect to time after the DW collision is shown for three different patterns of ferromagnetic nanowire with applied external fields of 26 mT (Fig. 2(a)) and 27 mT (Fig. 2(b)). Zero is chosen to be the time when the collision occurs.



(a) (b)

Fig. 2. Evolution of magnetization component M_z with respect to time for pattern A, pattern B, and pattern C after DW collision for the external fields of 26 mT and (b) 27 mT.



(a) (b)

Fig. 3. Frequency profile from FFT analysis of the magnetization ringing for M_z component after DW collision for pattern A, pattern B, and pattern C for the external field of (a) 26 mT and (b) 27 mT.

The full-width-half-maximum decay time of magnetization ringing is less than 1 ns for all three patterns. The magnetization ringing occurs in pattern A along both M_z directions with higher amplitude than in the case of pattern B and pattern C. On the other hand, the effect of adding ribbon patterns to the center of the ferromagnetic nanowire is attributed to the suppression of magnetization ringing after DW collision. After collision, the complex magnetization appears at the center and causes an increase in demagnetization energy, leading to magnetization ringing with energy dissipation. Introducing the small ribbon pattern attached to the center of the nanowire, as shown in patterns B and C, provides an extra channel for an energy dissipation, which results in a reduced amplitude of magnetization ringing. Note that this significant faster dissipation of magnetization ringing is achievable by merely attaching a small ribbon around the collision position at the wire. Fig. 3 shows the frequency profile determined from the fast Fourier transform (FFT) analysis of magnetization ringing along the M_z component after DW collision for all three patterns. When the external field is 26 mT along the M_z component, the frequency peaks are 9.290 ± 0.014 GHz (pattern A), 5.193 ± 0.007 GHz (pattern B), and 5.299 ± 0.008 GHz (pattern C). It becomes clear that the frequency profile is deviated by attaching the ribbon pattern of a simple wire. The frequency peaks from pattern B and from pattern C are lower than that from pattern A. It is particularly interesting to note that the frequency profile is not significantly changed by the tapering wire width (pattern C) from that of the wire with the attached ribbon, implying that introducing the ribbon pattern is a significantly more efficient way to suppress magnetization ringing in the wire than controlling wire width. The applied field strength of 26 and 27 mT is above the Walker breakdown, which is confirmed by complex DW dynamics rather than by a simple translational DW motion. Since DW motion in this field regime is accompanied by energetic inner spin dynamics, the FFT result of the case with 27 mT exhibits a rather complex profile. However, the peak position is still around 10 GHz, which is close to the peak position of the case with 26 mT (9.3 GHz). We consider that the peak position is not significantly changed within an error, which implies that ringing frequency is mainly determined by the DW annihilation process.

4. Conclusions

In conclusion, we investigated the magnetization ringing behavior after two domain walls collided with each other under an external field using micromagnetic simulation. We found that suppression of magnetization ringing could be achieved by attaching a small element such as a ribbon pattern to the location of the collision, thereby suggesting that the switching time of the magnetic bit could be reduced so that the recording speed could be faster. We also analyzed the magnetization ringing behavior by FFT, where the frequency peak of magnetization ringing decreases with the introduction of a ribbon pattern.

Acknowledgments

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