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Domain-wall trapping in controlled mesoscopic ferromagnetic wire junctions

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Abstract

The domain configurations in permalloy wires (30 nm thick, 1–50 μm wide and 210 μm long) with a central 'bowtie' (10 μm long) were investigated in both their demagnetized and remanent states using magnetic force microscopy (MFM) and the results were confirmed by micromagnetic calculations. Domain walls were found to be trapped at both ends of the bowtie, suggesting that domain-wall trapping is the dominant process in the magnetization reversal of these structures. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Domain structure; Magnetic force microscopy; Micromagnetic calculation; Microstructure

1. Introduction

A great deal of attention has been paid to the resistivity associated with electron scattering at magnetic domain walls [1–4]. Recent progress in nano-fabrication techniques enables researchers to identify the domain-wall scattering contribution from the magnetoresistance (MR) data [1,2]. However, both the experimental observations reported to date and theoretical models, which have been developed, are controversial [3,4]. Mesoscopic junction structures offer an attractive alternative route for localizing domain walls for such MR studies. As a first step in a prior study, the domain configurations were investigated in bridge structures, for which domain wall movement is the dominant magnetization reversal process [5].

In this study, we investigated ferromagnetic thin film junctions structured into 'bowties' which act to trap domain walls and for which the MR behavior can be investigated. Scanning probe microscopy (SPM, Digital Instruments, Nanoscope III) was used to reveal the effect of both the size and shape of the structures in the formation of domain walls, and this was supported by micromagnetic calculations.

2. Experimental procedure

The permalloy wire structures (30 nm thick, $1 \leqslant w \leqslant 50\,\mu\text{m}$ wide and 210 μm long) have a single central bowtie (10 μm long) at the center and were fabricated by molecular beam epitaxy techniques and electron beam lithography [5]. Using magnetic force microscopy (MFM) together with atomic force microscopy (AFM), the permalloy bowties were observed in both their demagnetized (as grown) and remanent states. A commercial Si probe (Digital Instruments, Pointprobe magnetic force sensor MESP) coated with CoCr was used and the distance between probe and sample was set as 5 nm for the AFM tapping mode and 100 nm for MFM measurements [5]. The tip of this probe was magnetized before each observation. A comparison of the domain configurations obtained from MFM and the results of micromagnetic calculations has been made.

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3. Results and discussion

Fig. 1 shows representative MFM images of the (a) 5 and (b) 10 μm wide permalloy bowties in the demagnetized states. No domain wall is seen at the junction in the wire width range $1 \leqslant w \leqslant 10\,\mu$m, indicating that the magnetization vector in the vicinity of the bowtie gradually rotates to align along the edge of the structures. However, with $w = 5\,\mu$m, a new domain appears in the vicinity of the bowtie (see right-hand side wire in Fig. 1(a)) and this domain forms domain walls (wall A in Fig. 1(b)) at both ends of the bowtie above $w = 10\,\mu$m. In addition, with increasing w, one wall (B), which connects the center of the bowtie and the wall A, is observed as shown on the right-hand side wire in Fig. 1(b). Qualitatively similar MFM images are seen when the demagnetizing cycle is repeated.

For non-connected bowties, on the other hand, a great number of walls are seen at the sharp end (see left-hand side wire in Fig. 1(c)) as previously reported [6]. It should be noted that the right-hand side of a non-connected bowtie possesses no domain wall, possibly due to dipolar interactions across the gap.

The bowties were also observed in the remanent state after applying a field (1 T) along the wires. As shown in Fig. 2, typically a new wall (D) appears at the center of the junction, suggesting that the gradual magnetization rotation state is a stable configuration in bowtie structures ($5 \leqslant w\,\mu$m). The wall A, on the other hand, stays at the same position as seen in the demagnetized state, which indicates that the domain wall A is stable and so the device behaves as a domain-wall trapping junction during the magnetization reversal process. In the remanent states following the application of a field perpendicular to the wires, the domain configurations are almost the same as those in the demagnetized state. These results suggest that the bowties are likely to be useful for domain-wall resistivity measurements.

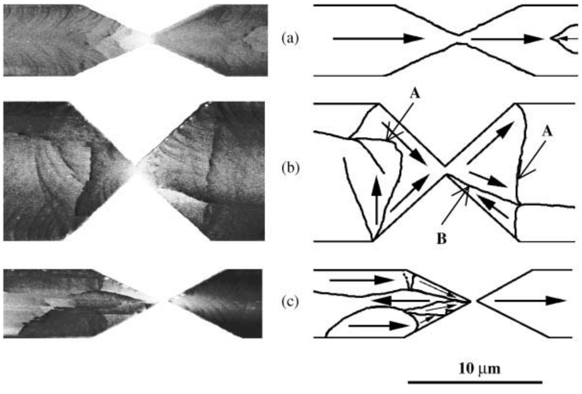

Fig. 1. MFM images of the permalloy wires (30 nm thick, w μm wide and 210 μm long: w = (a) 5 and (b) 10) with a narrow central bowtie (10 μm long) and (c) the unconnected bowtie ($w = 5\,\mu$m) in the demagnetized state.

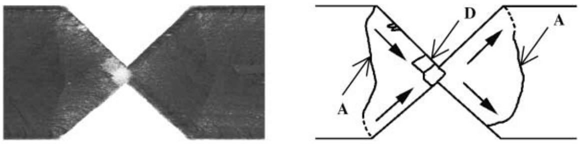

Fig. 2. MFM images of the permalloy bowtie (30 nm thick, 10 μm wide and 210 μm long) in the remanent state after the application of magnetic field along the wire.

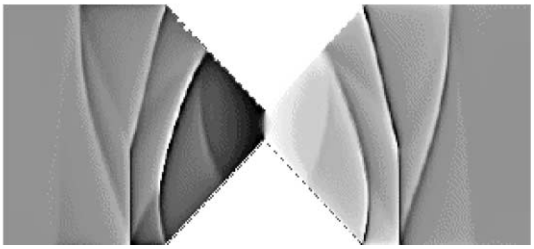

Fig. 3. Micromagnetic simulations for the permalloy bowtie (30 nm thick, 10 μm wide and 210 μm long).

Micromagnetic numerical calculations were carried out to simulate the domain wall configurations of the bridge structures using a finite difference method [3]. The results of numerical simulations for the connected bowtie structure with $w = 10\,\mu$m are shown in Fig. 3. In this picture, the magnitude of the divergence of the magnetization is shown by the gray scale, corresponding to the contrast seen in the MFM images. Fig. 3 shows that domain walls form at the ends of the bowtie structure, while single-domain states are seen at the wire region. These are in qualitative agreement with the MFM observation.

5. Conclusions

We have used MFM to investigate the domain configurations in permalloy wires (30 nm thick, $1 \leqslant w \leqslant 50\,\mu$m wide and 210 μm long) with a central bowtie (10 μm long) in both their demagnetized and remanent states. Domain walls are observed at the both ends of bowtie regions in the case of $10 \leqslant w\,\mu$m and are found to be very stable. This suggests that domain wall trapping is the dominant process in the magnetization reversal in these structures. The observed domain configurations are qualitatively supported by the results of micromagnetic simulations. The bowties with narrow wires suggest a possible way of detecting the domain wall resistivity in a low magnetic field, while providing insight into the domain wall reversal process in flat wire structures.

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