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Magnetization chirality due to asymmetrical structure in Ni-Fe annular dots for high-density memory cells

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Ni–Fe asymmetric ring dots with partially planed outer sides were investigated as candidates for high-density magnetic memory cells. The magnetic states, which were measured with magnetic force microscopy, show that in-plane magnetic fields can control the chirality, either clockwise or counterclockwise, of vortical magnetizations of the Ni–Fe asymmetric ring dots. This control facilitates applying ring dots to the magnetic random access memories. © *2004 American Institute of Physics.* [DOI: 10.1063/1.1667433]

I. INTRODUCTION

Magnetic random access memory (MRAM)[1] is a promising memory device because the MRAM is nonvolatile and displays high-speed potential. In the future, magnetic memory cells of the MRAM should be small and arranged at a high density to store large amounts of information. However, the high-density arrangement enhances the effects of stray fields from adjacent memory cells on each memory cell, and stray fields decrease the stability of the memory states as well as the uniformity of the switching fields.[2]

Using ring dots[3–6] is proposed in order to decrease the stray fields. Ring dots store information such as chirality of vortical magnetizations. In-plane magnetic fields cannot control the chirality in the ring dots.

Clockwise and counterclockwise magnetic fields were applied to control the chirality of the ring dots.[4] A current-flow perpendicular to the film plane created these magnetic fields. However, this method cannot be used for magnetic tunnel junctions (MTJs) because the MTJs include insulators. Therefore, high electric current cannot flow into the MTJs.

We have proposed that in-plane magnetic fields in asymmetric ring dots with partially planed outer sides can control the chirality of the vortical magnetization, either clockwise or counterclockwise, and our computational results based on the Landau–Lifshitz–Gilbert equation are consistent with this hypothesis.[7] Therefore, this study experimentally investigates the magnetization reversal with in-plane magnetic field in order to confirm that this method can control the chirality of the vortical magnetizations in asymmetric ring dots.

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II. EXPERIMENTAL PROCEDURES

Electron beam lithography, DC sputtering, and ion milling were used to microfabricate Ta(3 nm)/Ni-20 at %Fe(20 nm)/Ta(5 nm) asymmetric ring dots on Si(100) substrates with thermally oxidized layers whose thicknesses were 1.5 μm. The outer and inner diameters of the asymmetric ring dots were 850 and 450 nm, respectively. The distance between the edges of the asymmetric ring dots was 480 nm.

The magnetization processes of the asymmetric ring dots were observed using a longitudinal magneto-optical Kerr effect (MOKE) magnetometry at room temperature. The magnetic field was applied in-plane between -1.0 and 1.0 kOe. The shape of the asymmetric ring dots was observed by scanning electron microscopy (SEM) and magnetic force microscopy (MFM) observed the magnetic states of the asymmetric ring dots.

III. RESULTS AND DISCUSSION

Figure 1 shows the SEM images of typical asymmetric ring dots. Two types of asymmetric ring dot arrays, consisting of the dots shown in Fig. 1, were fabricated. The top

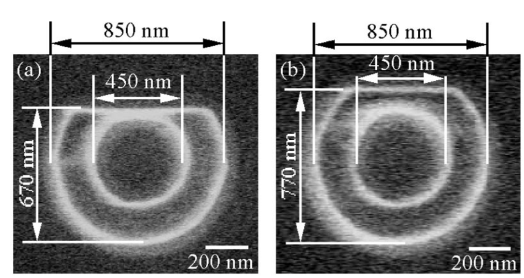

FIG. 1. SEM images and size of asymmetric ring dots. (a) A dot with relatively large planed parts in Dot Array A and (b) a dot with relatively small planed parts in Dot Array B.

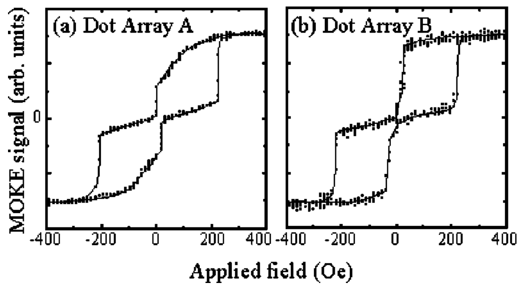

FIG. 2. MOKE hysteresis loops of asymmetric ring dots. The applied field is along the planed sides of asymmetric ring dots. (a) Dot Array A has relatively large planed parts and (b) Dot Array B has relatively small planed parts.

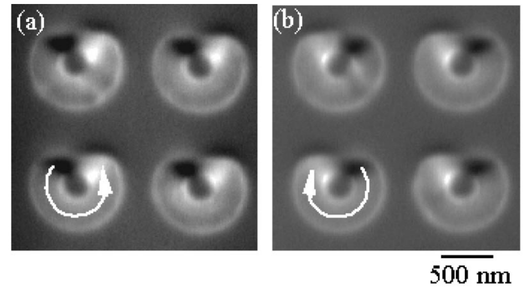

FIG. 3. MFM images at a zero field for Dot Array A with relatively large planed parts. (a) After applying a field in the right direction and (b) after applying a field in the left direction.

portion of the dots is straightly planed. The amounts of planed parts differ in Dot Arrays A and B. Dot Array A consists of dots with the relatively large planed parts [Fig. 1(a)] and Dot Array B has relatively small planed parts [Fig. 1(b)]. Both arrays have identical outer and inner diameters for the asymmetric ring dots, 850 and 450 nm, respectively.

Figure 2 shows the MOKE hysteresis loops of the asymmetric ring dots. The field was applied along the planed sides. As shown in Fig. 2(a), the MOKE signal is saturated at an applied field around 400 Oe for Dot Array A, which has relatively large planed parts. The asymmetric ring dots are believed to have unidirectional magnetizations when the dots are magnetically saturated. As the applied field is varied from a positive field of 400 Oe to a negative field of -400 Oe, the MOKE signal gradually decreases around 200 Oe. At an applied field around 0 Oe, the MOKE signal abruptly decreases and approaches zero. A MOKE signal near zero indicates that the asymmetric ring dots have vortical magnetizations. However, the chirality of the vortical magnetizations is unknown. The MOKE signal is almost constant between 0 and about -200 Oe, which implies that the vortical magnetizations are maintained between 0 and about -200 Oe. The MOKE signal abruptly decreases again at the applied field around -220 Oe and is negatively saturated between -300 and -400 Oe. The MOKE signal abruptly changes in an applied field near 0 Oe as the applied field is varied from a negative field of -400 Oe to a positive field of 400 Oe and the asymmetric ring dots have vortical magnetizations around 0 Oe. Vortical magnetizations are maintained between 0 and about 200 Oe. The MOKE signal abruptly increases near 200 Oe and is positively saturated between 300 and 400 Oe. For Dot Array B, which has relatively small planed parts, vortical magnetizations are caused at applied fields from 0 to -200 Oe as the field is decreased and from 0 to 200 Oe as the field is increased [Fig. 2(b)]. Like Dot Array A, the chirality of the vortical magnetizations is unknown for Dot Array B.

It is not possible to determine the chirality of the vortical magnetizations from the results in Fig. 2, so the MFM images of the asymmetric ring dots were observed. Before the observations, a 1 kOe field was applied along the planed sides of the dots and then it was removed. Figure 3(a) shows a MFM image of Dot Array A after positive saturation, where the field is applied in the right direction and then removed. A pair of black and white spots is seen near the planed side in each dot and the spots show stray fields from the planed sides. The white spots are located to the right of the black spots in Fig. 3(a), which demonstrates that the chirality of the vortical magnetizations is counterclockwise. On the other hand, as shown in Fig. 3(b), the white spots are located to the left of the black spots after negative saturation, where the field is applied in the left direction and then removed, which shows that the chirality of the vortical magnetizations is clockwise.

MFM observations were also conducted for Dot Array B, which has relatively small planed parts, in order to understand the effects of the amount of the planed parts on the chirality of the vortical magnetizations. Figure 4(a) shows the MFM image of Dot Array B after positive saturation. A pair of black and white spots is also observed near the planed side in each dot for Dot Array B. The white spots are located to the right of the black spots in Fig. 4(a), which indicates that the chirality of the vortical magnetizations is counterclockwise. In contrast, as shown in Fig. 4(b), after the negative saturation the white spots are located to the left of the black spots, which implies that the chirality of the vortical magnetizations is clockwise. The results of Fig. 4 confirm that the chirality of the vortical magnetizations is also controlled in dot arrays with the small planed parts.

Each dot-array investigated in this study contained about 4×10^5 dots. We observed the magnetization process for more than 100 dots and every dot displayed the same chirality of the vortical magnetizations as shown Figs. 3 and 4. Therefore, the error rate of the controlled chirality was less

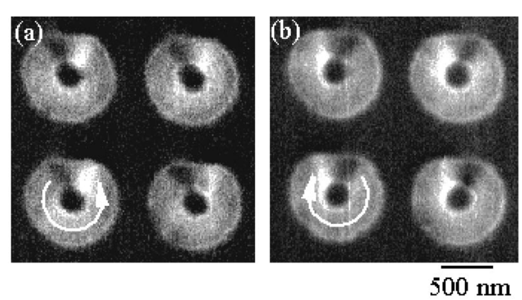

FIG. 4. MFM images at a zero field for Dot Array B with relatively small planed parts. (a) After applying a field in the right direction and (b) after applying a field in the left direction.

than 1%, but for smaller dots, which had an outer diameter of about 400 nm, the error rate increased to around 10% due to the irregularity of the dot shape.

Our micromagnetic simulation predicted that the chirality could be controlled.[7] The experimental results demonstrated that the in-plane magnetic field direction can control the chirality of the vortical magnetizations of the asymmetric ring dots from clockwise and counterclockwise. From the results of the micromagnetics simulation, it is understood that the direction of the high magnetic field turns the magnetization of the circular arcs, which are opposite from the planed parts. The direction of the magnetizations of the circular arcs is preferentially maintained with the direction of the magnetizations of the parts near the planed side, which determines the chirality of the vortical magnetizations, either clockwise or counterclockwise, in asymmetric ring dots. Therefore, the in-plane magnetic field direction can control the chirality of the vortical magnetizations in the asymmetric ring dots.

IV. SUMMARY

The magnetic states of the asymmetric ring dots were investigated using the MOKE magnetometry and MFM. The results of the MFM measurements experimentally demonstrate that the in-plane magnetic field direction can control the chirality of the vortical magnetizations, either clockwise or counterclockwise, of the asymmetric ring dots. Therefore, this method controls the chirality of the vortical magnetizations using asymmetric ring structures and the method may be the breakthrough that facilitates the application of the ring dots to MRAMs.

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