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Magnetic domain structure of Ni micro-ring observed by photoelectron emission microscope (PEEM)

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Introduction

The investigation of the magnetic domain structure of small magnetic elements is important for the implementation of the high-density data storage technique. For circular disks the flux closure (FC) domain with central vortex and/or single domain(SD) structures were reported[1][2]. In this paper we report the direct observation of the magnetic domain structure of Ni micro ring by using photoelectron emission microscope (PEEM) combined with x-ray magnetic circular dichroism (XMCD) technique. Such ring–shaped elements have the advantage that a FC structure can be stabilized without the formation of the central vortex, making the FC configuration the energetically more favorable state as compared to the SD state.

Experimental

A series of ring arrays were fabricated on the silicon wafer using electron beam lithography and lift-off techniques. The following rings with outer diameter (d_o) / inner diameter (d_i) were produced (in µm):10/8, 10/6, 10/5, 10/4, 10/2, 10/1, 5/4, 5/3, 5/2.5, 5/2, and 5/1. The thickness of the Ni rings were 40 nm. The rings were arranged in an array of 70 × 70 m^2 size with a separation equal to $d_o/2$. The XMCD-PEEM experiments were performed at room temperature. The circularly polarized soft x-ray light from the off-axis of the bending magnet radiation was injected to the sample at about 18 degree from the sample surface. The magnetic domain images were obtained by dividing the photoelectron images taken at the Ni L_3-edge (hν=877.2 eV) by those of at the L_2-edge (hν=852.7 eV).

Results and discussion

Figure 1(a) shows the magnetic domain images of the portion of the Ni micro-ring array with d_o/d_i = 10/5,4,2 and 1. The magnetic contrast obtained by the image-dividing method is directly related to the intensity of the magnetic moment on the projection to the light axis. Since the circularly polarized soft x-rays were illuminated from downward to upward, bright and dark regions in the image correspond to magnetic domains positively and negatively magnetized along the light axis. In the rings with d_o/d_i = 10/5, the gradual contrast change from bright region to dark region along the ring periphery is clearly observed. This contrast change corresponds to the FC domain structure as indicated in Fig.1 (b) by arrows showing the direction of the magnetic moment. In the case of the rings with d_o/d_i = 10/4, some rings show the onion like domain structure[3] as well as FC structure. The domain structure becomes more complex in the rings with smaller d_i and the rings with d_o/d_i =10/1 show almost multi domain structure. After applying the external magnetic field of about –400 Oe, every domain structure switched to almost perfect SD as shown in Fig. 1(c). Fig. 1(d) is the same as (a) but the d_o/d_i =5/2.5, 5/2, 5/1 and 5/0. As shown in the figure comparing to the larger size ring (d_o= 10 µm), smaller size (d_o= 5µm) ring tends to take a FC structure as recently observed by MFM[1]. Because of the absence of the central vortex in the rings, the exchange energy is reduced substantially and the trend of becoming SD which are observed for the smaller circular disk is suppressed in the ring geometry.

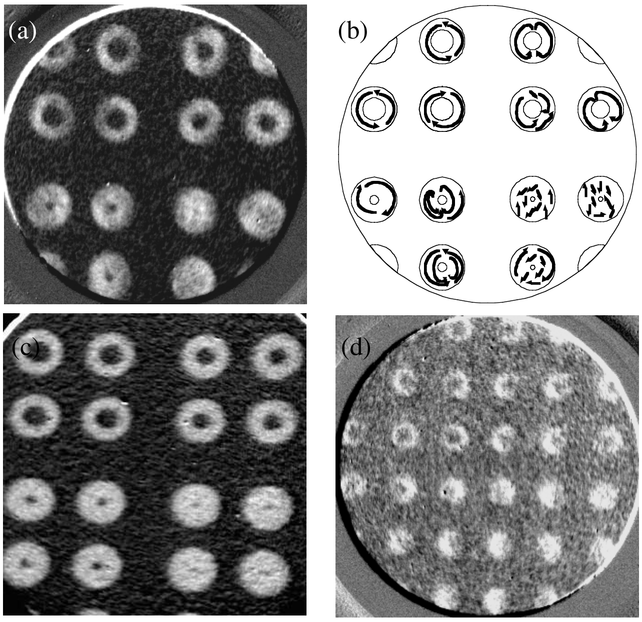

Fig.1 (a) Magnetic domain image of the Ni micro-rings measured by XMCD-PEEM. The outer and inner diameter of the rings are d_o/d_i (in µm) = 10/5, 10/4, 10/2, and 10/1. (b)The magnetic domain structures deduced from (a). Arrows show the direction of the magnetic moment. (c) The same as (a) but after applying magnetic field. (d) The same as (a) but the d_o/d_i =5/2.5, 5/2, 5/1, and 5/0.

References

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