Effects of Ion Implantation in Fabrication of Bit Patterned Media by Micro-XMCD Measurement

Hard disk drives (HDDs) adopting a perpendicular magnetic recording were commercialized in 2005. However, by conventional perpendicular magnetic recording using granular media, it is difficult to achieve an areal density of beyond 1 Tbit/in^2 because of thermal instability [1]. Bit-patterned media (BPM), in which a bit is recorded per magnetic dot arrayed periodically, has been proposed as the next-generation system. The BPM is expected as the most promising candidate systems for overcoming the restriction of thermal stability. We have studied techniques of design, fabrication and magnetic characterization in order to establish design guidelines for the BPM. In 2006, we demonstrated experimentally that when the dot-dot spacing, which is an important parameter for BPM design, is small, the recording performance deteriorates because of the magnetostatic interaction between dots [2]. In 2007, a sensitive element-specific hard X-ray micro-magnetometer at beamline **BL39XU** was used to characterize the magnetic properties of the Co-Pt dot arrays patterned by FIB with 30 keV Ga ions in a small area of μm order [3]. It was found that as the dot size decreases, the intensity of X-ray magnetic circular dichroism (XMCD) drastically decreases. This suggests that the dot edges were damaged magnetically by Ga ions implantation. The width of the damaged dot edge was estimated to be about 13 nm from the decrease in XMCD intensity [4]. This result suggests that BPM with an areal density of 1 Tbit/in^2 cannot be achieved by FIB with 30 keV Ga ions. Therefore, we proposed that ions with lower energies should be used to solve the problem and that the magnetic properties of Co-Pt dots fabricated by using Ar-ion etching with a energy as low as 200 eV should be evaluated.

Co-Pt magnetic dot arrays were prepared by directly etching a continuous film using electron beam (EB) lithography. Firstly, a 20-nm-thick $Co_{80}Pt_{20}$ continuous film with a perpendicular magnetic anisotropy was deposited by magnetron sputtering at room temperature. The anisotropy field (H_k) of the original film was estimated to be 8 kOe from the saturation field of the in-plane magnetization curve. In the subsequent process, dot arrays of an EB resist with a size of 20~100 nm and a dot-dot spacing of 100 nm were patterned by EB exposure. Finally, Co-Pt dot arrays were transferred through the EB resist mask by using Ar-ion etching with an energy of 200 eV. Figure 1 shows the SEM images of the Co-Pt arrays with dot sizes of 100, 70 and 20 nm before and after ion etching. All images show ideal sizes with regular alignments.

The magnetic properties of the Co-Pt dot arrays were evaluated by using the micro-magnetometer mentioned above, which is based on XMCD, as shown in Fig. 2. The magnetometer has a spatial resolution of 2.5 μm. XMCD signals were measured

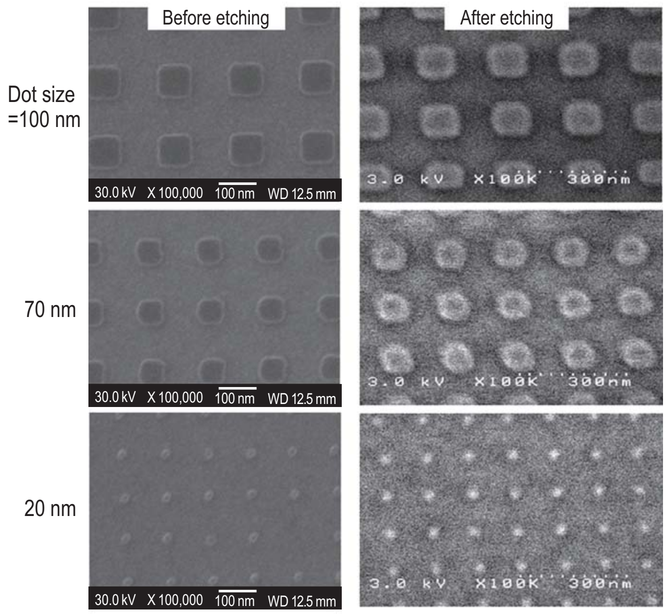

Fig. 1. SEM images of electron beam resist and Co-Pt magnetic dots before and after Ar ion etching.

in an X-ray fluorescence mode in which fluorescence yields were detected using a silicon drift detector. Element-specific magnetic hysteresis (ESMH) measurements were performed by changing the magnetic field and fixing the energy at the Pt L_3 edge ($h\nu$=11.56 keV) on the basis of the assumption that the XMCD amplitude of Pt is proportional to the total magnetization of the Co-Pt dots.

In Fig. 3, plots of closed circles show ESMH curves at the Pt L_3 edge of the original film (a) and dot arrays with various dot sizes (b-d) for an out-of-plane component. The ESMH curve of the 70 nm dot array patterned by FIB with 30 keV Ga ions is also shown by open circles in Fig. 3(c). Vertical axes of Fig. 3 denote that the XMCD intensities are normalized by Pt fluorescence yield, that is, they are proportional to the magnetic moment per Pt atom. Saturated XMCD intensities for dots of 100, 70 and 20 nm sizes were not reduced compared with that of the original film. It was found that the etching by low-energy Ar ions does not deteriorate the magnetization of the dots. Furthermore, the coercivity (H_c) of 20 nm dot arrays is 7.5 kOe, which is comparable to the H_k of the original film. By comparison with ESMH curves in Fig. 3(c) with 70 nm dot arrays, the H_c of the dot arrays fabricated by 200 eV Ar ions was found to be larger than that by 30 keV Ga ions. This may result from an accelerated deterioration of crystallinity or amorphization by Ga ion implantation. These results confirm that the etching using Ar ions cause slight damage on not only the magnetization but also the anisotropy field. It was concluded that the etching process using lower energy ions is effective for the realization of BPM with an areal density of 1 Tbit/in^2.

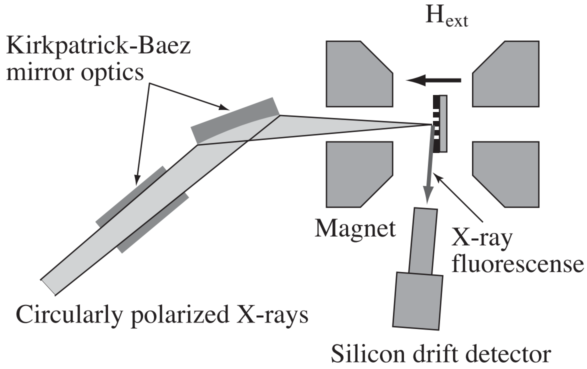

Fig. 2. Schematic view of element-specific hard X-ray micro-magnetometer based on X-ray magnetic circular dichroism.

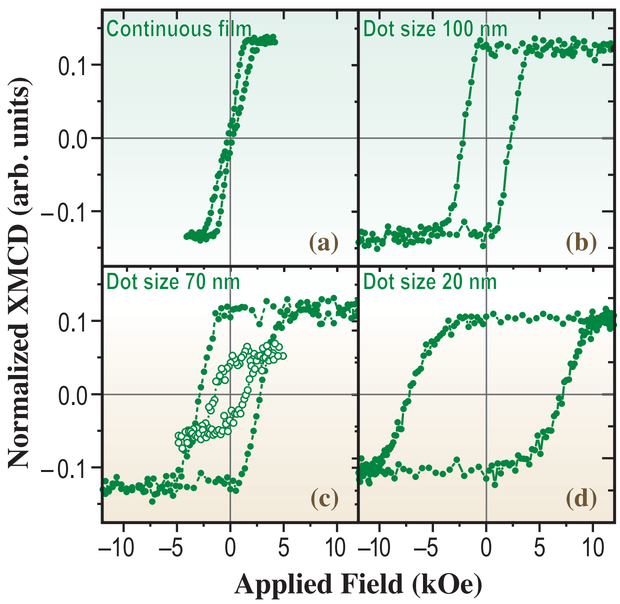

Fig. 3. ESMH curves at Pt L_3 edge of original film **(a)** and magnetic dot arrays with various dot sizes **(b-d)** obtained by 200 eV Ar ions. ESMH curves with 70 nm dots obtained by Ga ions with an energy of 30 keV are also shown in **(c)**.

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