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Observation of ferri-nonmagnetic boundary in $CrPt_3$ line-and-space patterned media using a dark-field transmission electron microscope

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ABSTRACT

Ion beam patterned $CrPt_3$ films were prepared by Kr^+ ion irradiation at a dose of 2×10^{14} ions/cm^2 onto $L1_2$-ordered $CrPt_3$ whose surface was partially masked by electron beam patterned resists. Cross-sectional observation using transmission electron microscopy was carried out to study the patterning boundary of the $CrPt_3$ film. Dark-field imaging showed a distinct contrast between non-irradiated ($L1_2$ phase) and irradiated (A1 phase) regions. The transition width between the two phases was estimated to be about 5 nm, which agreed well with the value simulated by a transport ion in matter (TRIM) code simulation.

1. Introduction

Bit patterned media (BPM) have attracted considerable interest as future high-density magnetic recording media because they provide a promising technology to solve the problem of the superparamagnetic limit, i.e., the thermal instability of recorded bits. BPM are usually fabricated by etching or milling a magnetic film through a defined mask to separate magnetic bits physically [1]. However, the problems for the practical use of such BPM are the rough surface due to discrete magnetic bits which disturb stable flying of the hard disk drive (HDD) head and the distribution of the switching field of the magnetic bits, which can cause recording errors. Ion beam irradiation has been proposed as a new approach to patterning magnetic materials locally without etching, i.e., without altering the surface topography [2], and ion irradiation into Co/Pt [2–5] and Co/Pd [6,7] multilayers has been reported. Their perpendicular anisotropies are locally modified by the ion irradiation. However, the adjacent magnetic bits are not magnetically isolated due to the exchange coupling through in-plane magnetized spacing [7], which limits the ultimate density of the media.

Previously, we reported that $CrPt_3$ films made on thermally oxidized Si substrate by sputtering deposition and post-annealing exhibit a perpendicular magnetic anisotropy with a K_u of 5×10^6 erg/cm^3 [8,9], and that 30 keV Kr^+ ion irradiation with a quite low dose of 2×10^{14} ions/cm^2 suppresses the ferrimagnetism of $CrPt_3$. We have also reported that the HDD head flyable planer bit patterned media can be fabricated using this ion beam poisoning [8]. The loss of magnetization due to Kr^+ ion irradiation is described by the phase change of $CrPt_3$ from the ferrimagnetic $L1_2$ to paramagnetic A1 phase [9]. Since the low ion dose drastically changes the magnetism of $CrPt_3$, high-density planar BPM without exchange coupling between magnetic bits are expected. In this study, in order to discuss how small magnetic bits can be fabricated by the ion irradiation method, dark-field transmission electron microscopy (TEM) observation was carried out to image the ferrimagnetic region and evaluate the transition width between ferrimagnetic ($L1_2$ phase) bit and nonmagnetic (A1 phase) space regions.

2. Experiment

In order to enhance the contrast in dark-field TEM images, epitaxial $CrPt_3$ films grown on MgO substrates were studied in this report, although the $CrPt_3$ on MgO does not exhibit a large perpendicular anisotropy [10]. (0 0 1) oriented $L1_2$-phase $CrPt_3$ films (20 nm) were epitaxially grown on MgO (0 0 1) substrates at 650 °C by a molecular beam epitaxy (MBE) system. To improve the $L1_2$ ordering, the samples were post-annealed at 850 °C for 5 min in the MBE chamber. The $CrPt_3$ layer was deposited by the co-evaporation of independently controlled Cr and Pt e-beam sources. The deposition rates of Cr and Pt were set to 0.05 Å/s and

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0.19 Å/s, respectively. For the fabrication of ion irradiation patterned film, line-and-space ZEP520A resist masks were first created on the $CrPt_3$ films using an electron beam lithography system. Then, 30 keV Kr^+ ions at a dose of 2×10^{14} ions/cm^2 were uniformly irradiated on the patterned masks. For the Kr^+ irradiation, the beam current density of the Kr^+ irradiation was set at 0.25 μA/cm^2. After the irradiation, an Al (100 nm) layer was sputter-deposited as a protective layer for the subsequent focused ion beam (FIB) thinning for TEM sample preparation. An additional protective layer of C was deposited using FIB-assisted chemical vapor deposition before the thinning, and then the sample was thinned down to a thickness of about 70 nm in order to carry out cross-sectional observations using 1000-kV TEM (Hitachi H-1250ST). The magnetic structure of the line-and-space patterned $CrPt_3$ was studied by magnetic force microscopy (MFM). For this purpose, perpendicular magnetized $CrPt_3$ is necessary, and thus an $L1_2$-phase $CrPt_3$ polycrystalline film on thermally oxidized Si substrate was also prepared. The preparation method of the polycrystalline $CrPt_3$ was the same as that in the previous report[9], i.e., sputtering deposition of [Cr (0.4 nm)/Pt (1.69 nm)]$_{10}$ MLs followed by vacuum annealing at 850 °C. The line-and-space patterning was carried out in the same manner as that mentioned above, but after the Kr^+ ion irradiation, the resist was removed by O_2 ashing using a reactive ion etching system. The structure and

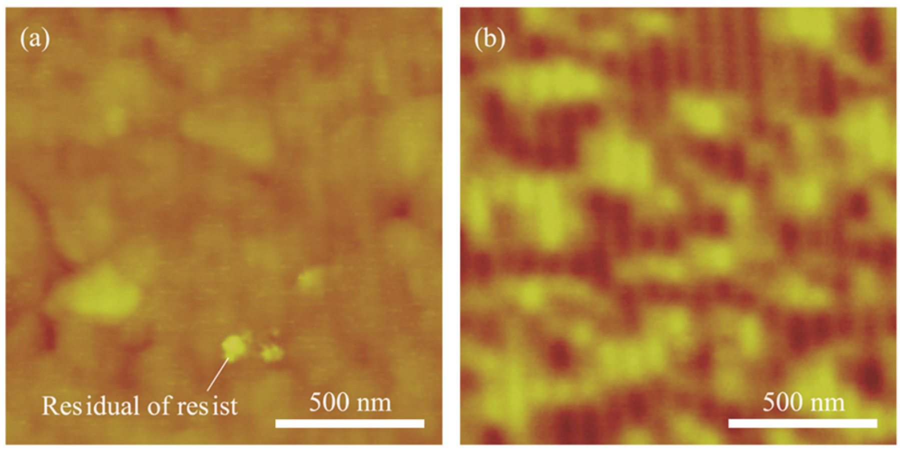

Fig. 1. (a) AFM and (b) MFM images of line-and-space patterned $CrPt_3$ films fabricated on thermally oxidized Si substrate. The pitch of the line and space is 80 nm.

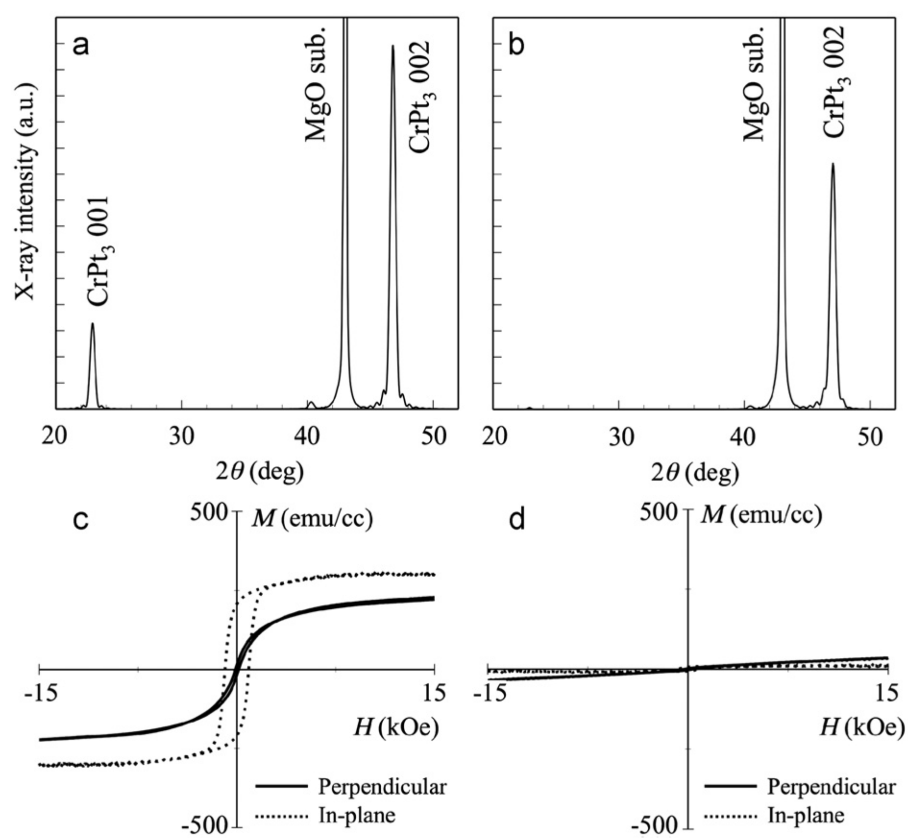

Fig. 2. X-ray diffraction patterns of the MBE-grown $CrPt_3$ film (a) before and (b) after Kr^+ ion irradiation at 2×10^{14} ions/cm^2. Hysteresis loops of the $CrPt_3$ before and after the Kr^+ irradiation are shown in (c) and (d), respectively, where the loops were taken applying a magnetic field parallel and perpendicular to the film plane.