Fabrication of Discrete Track Media by Cr Ion Implantation

Tatsuya Hinoue[1], Toshinori Ono[1], Hiroshi Inaba[2], Tomohiro Iwane[1], Hiroshi Yakushiji[1], and Akiyoshi Chayahara[3]

[1]Central Research Laboratory, Hitachi Ltd., Odawara 256-8510, Japan
[2]Production Engineering Research Laboratory, Hitachi Ltd., Yokohama 244-0817, Japan
[3]National Institute of Advanced Industrial Science and Technology, Ikeda 563-8577, Japan

Discrete track media were successfully fabricated by Cr ion implantation. The saturation magnetization of the CoCrPt-SiO$_2$ perpendicular recording layer was decreased down to 6% by implanting Cr ions with a dosage of 1×10^{17} ions/cm^2 and an ion energy of 20 keV. A resist mask with a discrete track pattern was prepared by e-beam lithography and the pattern was transferred to the recording layer by Cr ion implantation. A clear magnetic contrast of the tracks was observed and the average surface roughness was maintained less than 1 nm. A clear servo signal was obtained by spin-stand measurement using a flying head. Feasibility of discrete track media fabrication by Cr ion implantation was confirmed.

Index Terms—**Discrete track media, ion implantation, perpendicular recording, plane surface.**

I. INTRODUCTION

PATTERNED media are one of the most promising technologies for future high density recording. Etching is one of the approaches to fabricate patterned media [1]–[3], which realizes physical separation of tracks or bits. In this method, the grooves should be refilled and planarized to get a plane surface for good head flyability. On the other hand, ion implantation is another approach [4]–[8], which realizes magnetic separation of tracks or bits by changing the magnetic properties of the recording layer locally. This method is advantageous to good flyability, because refilling and planarization processes are not necessary. In this study, we investigated the effect of Cr ion implantation on reducing the magnetization of the recording layer and applied it to the discrete track media (DTM) fabrication.

II. EXPERIMENTAL PROCEDURE

CoCrPtB capped CoCrPt-SiO$_2$ perpendicular recording media with a Ru intermediate layer were deposited on NiP-plated aluminum substrates or silicon substrates by DC magnetron sputtering. The thickness of the CoCrPtB capping layer and the CoCrPt-SiO$_2$ granular layer were 7 and 13 nm, and the saturation magnetization of the capping layer and the granular layer were 0.82 and 0.69 T, respectively. Cr$^+$ ions were implanted into the media by means of plasma based ion implantation (PBII) [9]. Magnetization measurements were done to investigate the optimum dosage and ion energy for the effective reduction of magnetization by using a vibrating sample magnetometer (VSM). The media without a soft magnetic underlayer (SUL) were prepared for the VSM measurements. The elemental composition was measured by a secondary ion mass spectrometer (SIMS). Cr ion implantation and resist removal were done to the media with a 140 nm-thick resist film to investigate the affect of the resist removal process on the magnetic properties.

A 140 nm-thick resist mask including track and servo patterns was formed on the media surface by e-beam lithography, and Cr$^+$ ions were implanted into the media to fabricate the DTM. A carbon overcoat and a lubricant were formed on the media after the mask removal, and a magnetic field of 800 kA/m was applied to magnetize the pre-patterned servo. The surface topography and the magnetic domain structure were measured by an atomic force microscopy (AFM) and a magnetic force microscopy (MFM), respectively. The cross-sectional microstructure and the elemental composition were measured by a transmission electron microscopy (TEM) and an energy dispersive X-ray fluorescence spectrometer (EDX), respectively. The measurement spot diameter of the EDX was 4 nm. A spin-stand reading test was done with a flying height of 9 nm and a rotation speed of 5400 rpm at the radius of 21.5 mm. A head with a tunnel magnetoresistive (TMR) read element was used for the reading test.

III. RESULTS AND DISCUSSION

A. Investigation of Magnetization Reduction

First, a suitable ion energy for the Cr ion implantation was calculated. We applied the following equation to calculate the nuclear stopping power using a modified Thomas-Fermi potential [10].

$$\frac{dE}{dx} = N\sigma_n = 4\pi a N Z_1 Z_2 C_0 e^2 \frac{M_1}{M_1 + M_2} s(\varepsilon)\ (\mathrm{J/m}) \quad (1)$$

where σ_n is the nuclear stopping cross section, $a = 0.885 a_0 / (Z_1^{1/2} + Z_2^{1/2})^{2/3}$ is the Thomas-Fermi radial, $C_0 = 1/4\pi\varepsilon_0$, $s(\varepsilon) = d\varepsilon/d\gamma$ is the dimensionless nuclear stopping power, $N = N_\mathrm{a}\rho/M_2$ is the target atom density, Z_1 and M_1 are the atomic number and the mass of incident ion, and Z_2 and M_2 are the atomic number and the mass of target, respectively. The assumed ion was Cr$^+$ where $Z_1 = 24$ and $M_1 = 52$, and the assumed target was CoCrPt alloy where $\rho = 10.0$ g/cm^3, $Z_2 = 36$ and $M_2 = 83$. Fig. 1(a) and (b) shows the calculation results of the energy loss and the implanted depth, respectively. When the ion energy was low, the depth was not linear to the ion energy because the energy loss

Manuscript received October 30, 2009; revised January 29, 2010; accepted February 08, 2010. Current version published May 19, 2010. Corresponding author: T. Hinoue (e-mail: tatsuya.hinoue.wx@hitachi.com).

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Digital Object Identifier 10.1109/TMAG.2010.2043416

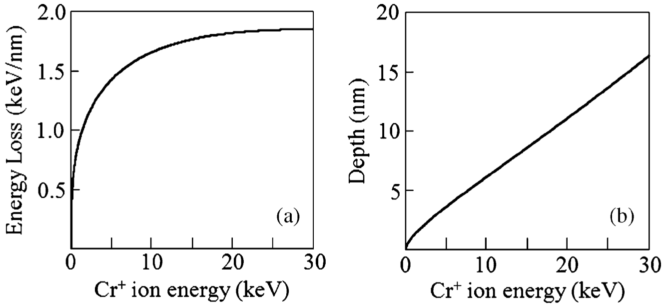

Fig. 1. Calculation results of (a) energy loss and (b) depth in implanting Cr^+ ions into CoCrPt alloy.

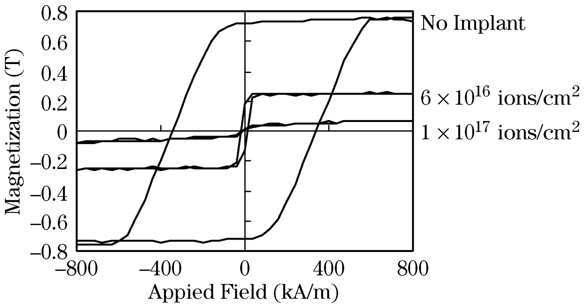

Fig. 2. M-H curves of the media before and after the Cr ion implantation.

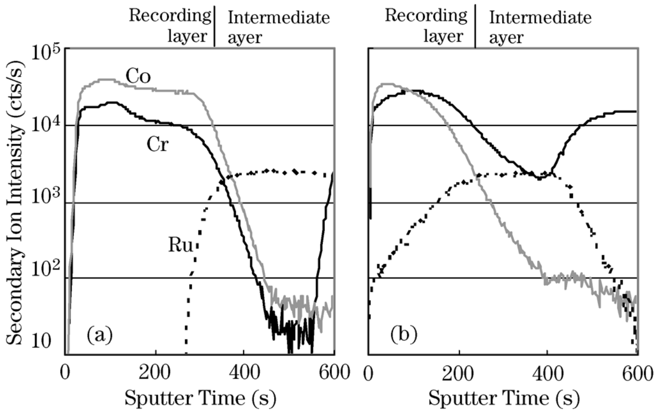

Fig. 3. Elemental composition profiles by SIMS (a) before the implantation and (b) after the implantation at 1×10^{17} ions/cm^2 and 20 keV.

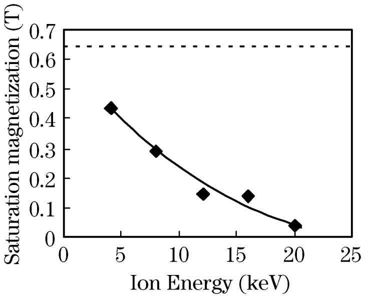

Fig. 4. Dependence of the satulation magnetization on the ion energy for the dosage of 8×10^{16} ions/cm^2.

increased rapidly. When the ion energy got high, the energy loss was near to constant and the depth was almost linear to the ion energy. When thickness of the recording layer was 20 nm, the suitable ion energy for implanting Cr^+ ions to the center depth of the recording layer was about 20 keV.

Based on the calculation results, the Cr ion implantation was done with the ion energy of 20 keV. Fig. 2 shows the M-H curves of the media before and after the Cr ion implantation. The saturation magnetization was decreased to 33% and 6% at the dosage of 6×10^{16} and 1×10^{17} ions/cm^2, respectively.

Fig. 3(a) and (b) shows the elemental composition profiles measured by SIMS for the medium without the implantation and that with the dosage of 1×10^{17} ions/cm^2 and the ion energy of 20 keV. The cross point of Co and Ru intensity lines was considered to be the boundary between the recording layer and the Ru intermediate layer. A part of the recording layer, which was corresponding to the thickness of 4 nm, was etched by the implantation. The saturation magnetization was decreased by 23% by this physical thickness reduction. But, another 71% reduction of the saturation magnetization was the effect of the Cr ion implantation. Increase of the Cr in the recording layer was observed in the SIMS profiles, and the maximum point of the Cr was around center depth of the recording layer. It was consistent with the calculation result. Some Cr ions were implanted into the Ru intermediate layer, and Ru migration from the intermediate layer to the recording layer was observed. The magnetization reduction was mainly caused by the increase of the implanted Cr, and the Ru migration into the recording layer assisted it.

The Cr ion implantation with the dosage of 1×10^{17} ions/cm^2 and the ion energy of 20 keV and the resist removal were done to the media with the resist film. The saturation magnetization didn't change before and after the resist removal. The coercivity was increased by 7% after the resist removal, but the affect of the resist removal on the magnetic properties was small.

The dependence of the saturation magnetization on the ion energy is shown in Fig. 4. The dosage was 8×10^{16} ions/cm^2 for each ion energy. The saturation magnetization decreased as the ion energy increased. The saturation magnetization was decreased by over 70% at 12 keV and almost disappeared at 20 keV. From the calculation results, the implantation depth was shallower than the center of the recording layer when the ion energy was less than 20 keV. In that case, the effect of the implantation was not enough. For the effective magnetization reduction, the Cr ions should be implanted into the center of the recording layer.

B. Fabrication of Discrete Track Media

Fig. 5(a) and (b) shows the cross-sectional microstructure and the concentration profile of the recording layer obtained by TEM and EDX, respectively. The dosage was 6×10^{16} ions/cm^2 and the ion energy was 20 keV. The resist thickness got about a half by the etching effect of the implantation. The Cr concentration in the implanted area was about 30 at.%, that was larger by about 15 at.% than that in the masked area, around 3 nm-depth from the recording layer. The concentration of Cr in the center depth of the recording layer is considered to be much larger than 30 at.% in the implanted area because the aimed depth of the implantation was around the center of the recording layer. The Cr

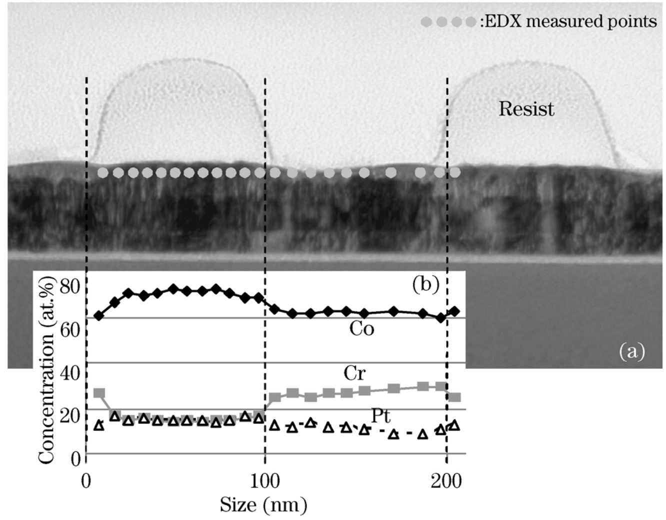

Fig. 5. The cross-sectional TEM image and the EDX profile for DTM fabricated by the Cr ion implantation: (a) TEM image; (b) EDX profile.

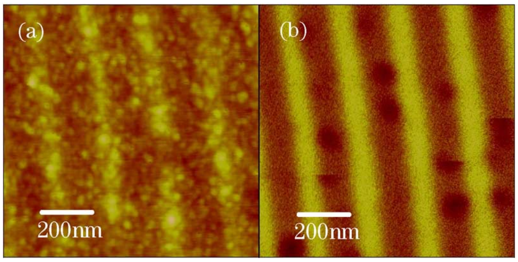

Fig. 6. AFM and MFM images for the fabricated DTM after removing the mask and magnetizing the recording layer: (a) AFM image; (b) MFM image.

concentration over 30 at.% in the recording layer is enough for effective reduction of the magnetization.

Fig. 6(a) and (b) shows the surface topography and the magnetic domain structure of the fabricated DTM measured by AFM and MFM, respectively. The dosage was 1×10^{17} ions/cm^2 and the ion energy was 16 keV. The ion energy was reduced considering the ion stopping ability of the mask. The peak-to-valley height of the AFM image was 3.3 nm and the average surface roughness (Ra) was less than 1 nm. A clear magnetic contrast of the 200 nm-pitch track pattern was observed on the MFM image. The track pattern of the DTM was obtained by the Cr ion implantation.

Read-back wave form measured by spin-stand for the DTM with the dosage of 1×10^{17} ions/cm^2 and the ion energy of 16 keV was shown in Fig. 7. A clear servo signal was observed, and the feasibility of the DTM fabrication by Cr ion implantation was confirmed.

IV. CONCLUSION

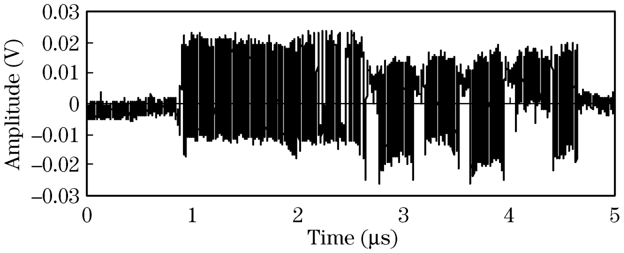

Fig. 7. The read-back wave form from the servo area of DTM fabricated by the Cr ion implantation.

Discrete track media were fabricated by reducing the magnetization of the recording layer locally using Cr ion implantation. The saturation magnetization of CoCrPtB capped CoCrPt-SiO$_2$ perpendicular recording media decreased and almost disappeared by implanting Cr ions into the recording layer. The magnetization reduction caused an increase of Cr in the recording layer mainly, and an increase of Ru migrated from the intermediate layer assisted it. For the fabricated DTM, a clear magnetic contrast of the 200 nm-pitch track was observed on a plane surface whose Ra was less than 1 nm, and a clear servo signal was obtained. It was found that Cr ion implantation was very effective for easier fabrication of patterned media with enough plane surface to get good head flyability.

ACKNOWLEDGMENT

The authors would like to thank Y. Kawato and K. Ito of the Central Research Laboratory, Hitachi Ltd., for measurement of the spin-stand data.

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