Study of Gas Cluster Ion Beam Planarization for Discrete Track Magnetic Disks

Keisuke Nagato[1,2], Hiroshi Tani[3], Yasuo Sakane[4], Noriaki Toyoda[5], Isao Yamada[5], Masayuki Nakao[1], and Tetsuya Hamaguchi[1]

[1]Department of Engineering Synthesis, School of Engineering, University of Tokyo, Tokyo 113-8656, Japan
[2]Japan Society for the Promotion of Science, Tokyo 102-8472, Japan
[3]Hitachi Global Storage Technologies Japan, Ltd., Kanagawa-ken 256-8510, Japan
[4]Western Digital Media Operations, San Jose, CA 95131 USA
[5]Incubation Center, Graduate School of Engineering, University of Hyogo, Hoyogo-ken 671-2280, Japan

We studied planarization of carbon overcoat by gas cluster ion beam (GCIB) for discrete track magnetic disks. We fabricated discrete tracks with variant pitches by focused ion beam on a 30-nm-thick carbon overcoat deposited on magnetic disks, and we planarized them with an Ar GCIB using lateral sputtering effect. It was found that planarization by GCIB was more effective for lower wavelengths than for those with a few hundreds nanometers. On the discrete tracks with 100-nm pitch and 20-nm depth, the initial peaks and valleys were removed by GCIB; however, on the ones with over 200-nm pitch, the initial peaks and valleys remained though the heights were drastically decreased. These results indicate the capability of GCIB planarization as a process for the discrete track media. Furthermore, cross sections were observed by transmission electron microscopy. The GCIB with relatively low dose could also planarize the 120-nm-pitch carbon tracks without etching the magnetic layer.

***Index Terms*—Carbon overcoat, discrete track magnetic disks, gas cluster ion beam, planarization.**

I. Introduction

As advances in areal densities are applied to magnetic recording, disk drive storage systems are considered very economical. Discrete track media and bit patterned media are strong candidates to achieve higher areal density greater than 1 Tb/in^2 [1]–[6]. Both of these technologies pose many challenges. The grooved surface of discrete track media leads to head slider flying instability. Soeno [3] proposed a flattening process with two steps: SiO_2 deposition with a bias power supplied to the substrate and etching the extra SiO_2. Moneck [6] studied the slider flyability of patterned media and showed that plane surfaces will promote more slider flyability.

Recently, a gas cluster ion beam (GCIB) technology has been proposed as a novel smoothing technique [7], [8]. Cluster ions are aggregations of a few or several thousands of atoms or molecules. Cluster ions have extremely low energy and have a characteristic of lateral sputtering without deep implantation of ions. Various gases such as Ar, O_2, and SF_6 have been investigated as etching gases to Si, metals, or ceramics [7]. GCIB has the potential to planarize discrete tracks in a dry process.

Here, we assume refilling the grooves of discrete magnetic tracks by carbon and etching the extra carbons. For this smoothing technique, we studied Ar GCIB planarization of pseudo-tracks fabricated by focused ion beam (FIB) on a 30-nm-thick carbon overcoat deposited on magnetic disks.

Digital Object Identifier 10.1109/TMAG.2008.2001618

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

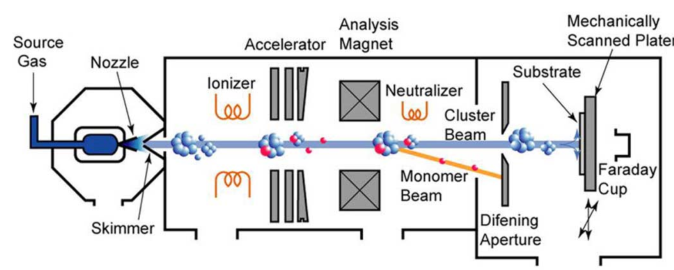

Fig. 1. Schematic diagram of GCIB apparatus.

II. Experiment

A. GCIB Apparatus

Fig. 1 shows a schematic diagram of the GCIB irradiation apparatus. The neutral cluster beam is generated from a high pressure Ar gas through a nozzle and a skimmer. Subsequently, the neutral clusters are ionized by electron bombardments. In this paper, the clusters formed had 3000 atoms at maximum in the distribution. Acceleration energy for an ionized cluster was 20 keV and doses were 5×10^{15} and 2×10^{15} ion/cm^2.

B. Experimental Method

Fig. 2 shows a schematic of an experimental method to investigate the planarization of carbon tracks. The disks used have seed/under layer, magnetic layer, and a thin carbon overcoat. We deposited the 30-nm-thick carbon overcoat by chemical–vapor deposition on the magnetic disks. The tracks of varying pitches were fabricated by FIB (FB-2000A, Hitachi). Track pitches were varied between 93 and 430 nm, and the depths were 15–20 nm.

In the FIB, focused Ga^+ ions were irradiated onto the thick carbon overcoat with an acceleration voltage of 30 kV and with a spot size of 30–50 nm. The fabricated area size was 8 by 8 μm.

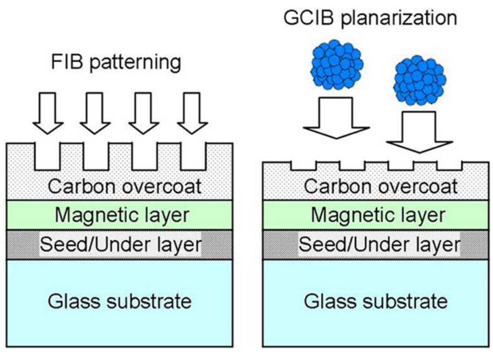

Fig. 2. Experimental method.

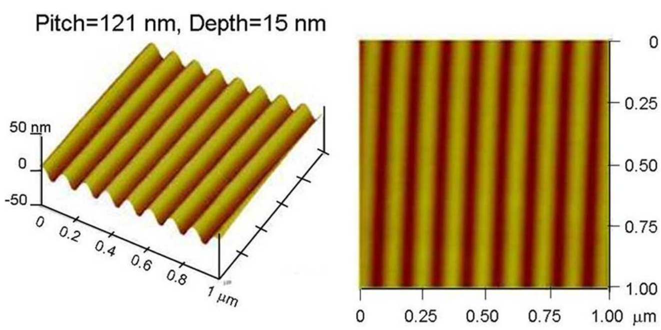

Fig. 3. AFM images of typical sample.

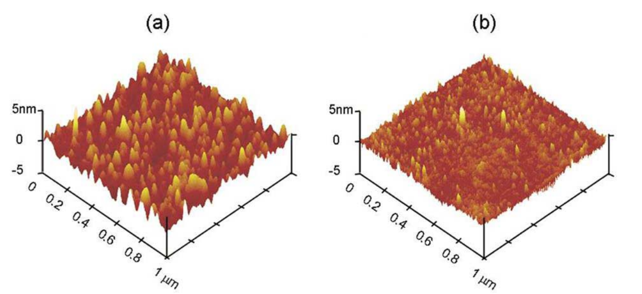

Fig. 4. Roughness of nonpatterned regular disk (a) before GCIB and (b) after GCIB.

Fig. 3 shows atomic force microscopy (AFM) images of a typical sample (pitch: 121 nm, depth: 15 nm).

GCIB were irradiated on the samples. We compared the roughness before and after GCIB irradiation by AFM. Cross sections of some samples were observed by transmission electron microscopy (TEM).

III. Results and Discussion

A. Planarization Effect of GCIB on Nonpatterned Regular Disks

To understand the roughness induced by GCIB, we irradiated GCIB on a nonpatterned regular disk. The acceleration voltage was 20 kV and the dose was 5×10^{15} ion/cm^2. Fig. 4 shows AFM images of the surfaces before and after GCIB. The average roughness (Ra) of the original surface was 0.80 nm and that after GCIB was 0.38 nm. Fig. 5 shows the power spectra. The roughness at the wavelengths of under 200 nm was significantly decreased by GCIB.

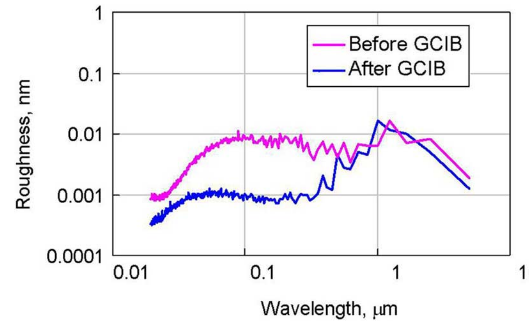

Fig. 5. Surface amplitudes of nonpatterned regular disk by GCIB planarization.

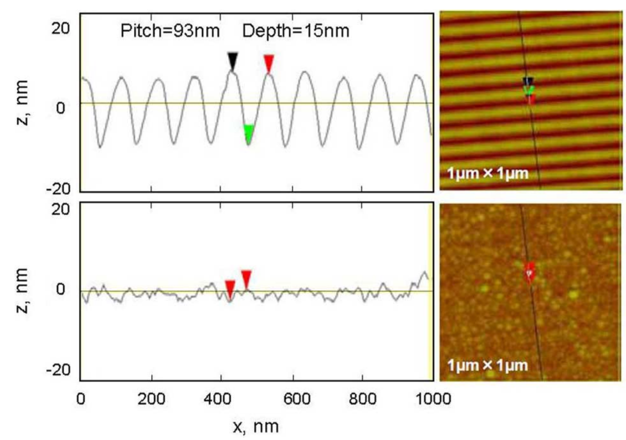

Fig. 6. Surface roughness before/after GCIB (pitch: 93 nm, depth: 15 nm).

B. Comparison of Surface Roughness of Discrete Tracks Before and After GCIB

We compared the surface roughness of samples before and after GCIB. The acceleration voltage was 20 kV and the dose was 5×10^{15} ion/cm^2. Fig. 6 shows the AFM comparison of the surface roughness of the sample with the track pitch of 93 nm. The tracks with 15-nm depth were formed by FIB, and the tracks were clearly obliterated by GCIB. Ra after GCIB was decreased from 5.5 to 0.85 nm. Figs. 7–9 show the AFM results of the tracks with 172/312/430 nm pitch and 20/17/16 nm depth, respectively. The peak-to-valleys were drastically decreased by Ar GCIB in each track pitch.

C. Power Spectrum Comparison of Surface Roughness of Discrete Tracks Before and After GCIB

Fig. 10 shows the comparison of the power spectra of the surface roughness. The roughness of the low harmonic cycle of 93-nm pitch was high in the sample before GCIB; on the other hand, the roughness of the sample after GCIB has no dependence on wavelength of 93 nm. We carried out the power spectrum analyses on the samples with other track pitches. Fig. 11 shows the amplitude reduction rate at the wavelengths of the FIB-fabricated track pitches, which are defined as rates of the

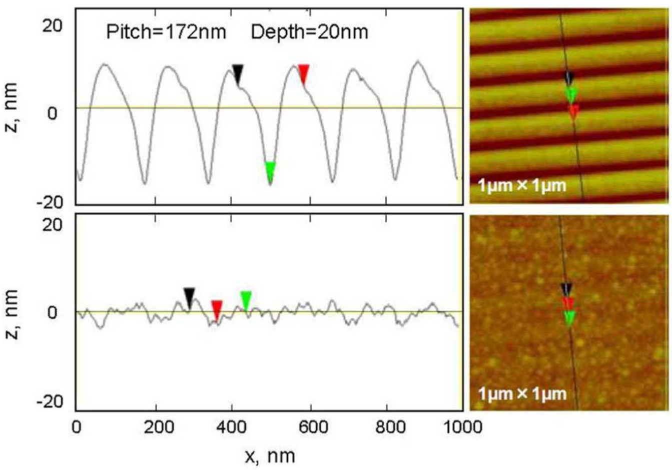

Fig. 7. Surface roughness before/after GCIB (pitch: 172 nm, depth: 20 nm).

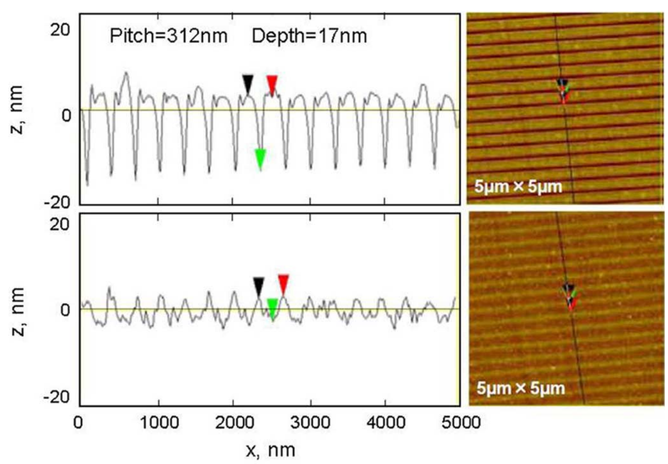

Fig. 8. Surface roughness before/after GCIB (pitch: 312 nm, depth: 17 nm).

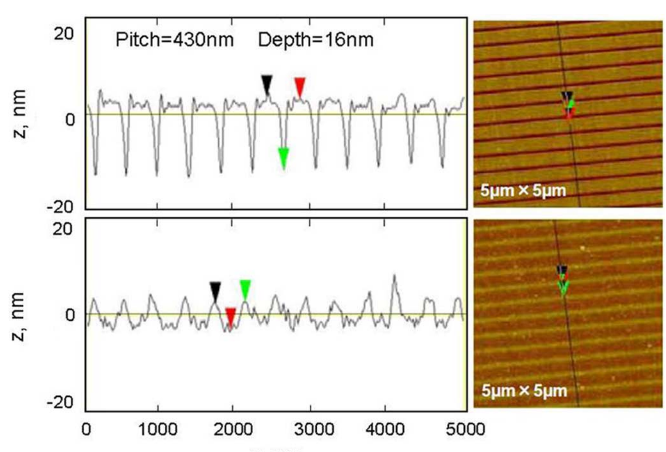

Fig. 9. Surface roughness before/after GCIB (pitch: 430 nm, depth: 16 nm).

amplitudes after GCIB divided by those before GCIB. The reduction rate increases with increases of the pitch. Discrete track media will be used in the high density recording region with track pitch of under 200 nm. Therefore, GCIB planarization is

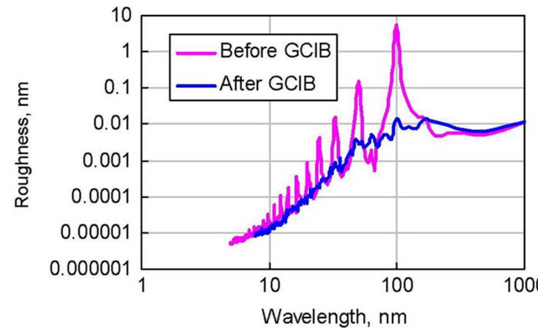

Fig. 10. Power spectrum comparison of surface profiles on the sample with track pitch of 93 nm.

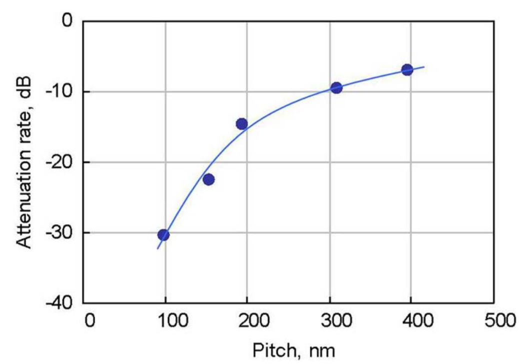

Fig. 11. Pitch dependence of roughness attenuation rate.

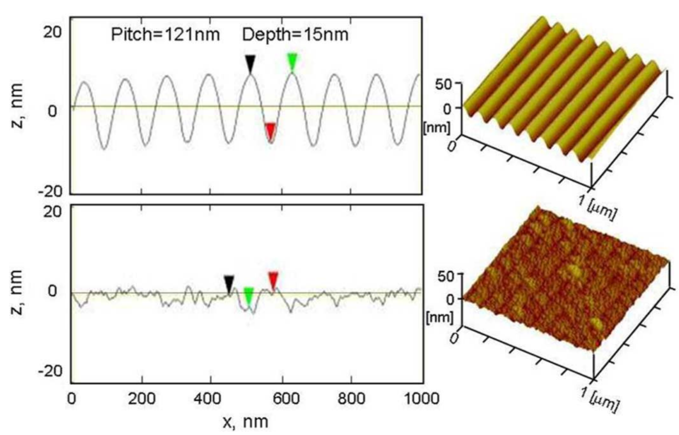

Fig. 12. Surface roughness before/after GCIB (acceleration voltage: 20 kV, dose: 2×10^{15} ion/cm^2).

supposed to be useful, especially for the narrower track region of discrete track media.

D. TEM Observation of Cross Sections of Discrete Tracks Before and After GCIB

We carried out the TEM observation of the cross sections of the carbon tracks before and after GCIB. Here, the acceleration voltage of Ar GCIB was 20 kV and the dose was 2×10^{15} ion/cm^2. Fig. 12 shows the AFM images of the tracks. The pitch and depth of the tracks fabricated by FIB were 121 and 15 nm, respectively. Fig. 13 shows the TEM images of the cross sections of the tracks (a) before and (b) after GCIB. In Fig. 13(a), the areas in magnetic layer under carbon grooves are

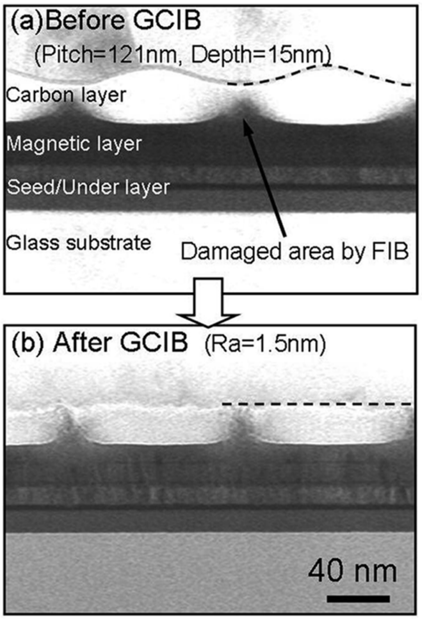

Fig. 13. TEM images of the cross sections of carbon tracks (a) before and (b) after GCIB (acceleration voltage: 20 kV, dose: 2×10^{15} ion/cm^2).

not crystalline, thus these areas were damaged by FIB. The Ra of the carbon surface after GCIB irradiation was 1.5 nm. The GCIB planarized the carbon tracks without reaching the magnetic layer.

IV. Conclusion

We investigated Ar GCIB planarization using regular magnetic disk surface and pseudo-tracks with varying pitches patterned by FIB on the 30-nm-thick carbon overcoat deposited on magnetic disks. Ar GCIB has been demonstrated to be an effective method to planarized discrete track surfaces by lateral etching effect. Planarization efficiency depends highly on track pitches. The GCIB planarization is practical and consistent for carbon tracks with pitches under 200 nm. According to the TEM observations of cross sections, it was demonstrated that GCIB could planarize the carbon tracks without reaching the magnetic layer.

Acknowledgment

This work was supported in part by the Storage Research Consortium (SRC).

References

[1] B. D. Terris and T. Thomson, “Nanofabricated and self-assembled magnetic structures as data storage media,” *J. Phys. D: Appl. Phys.*, vol. 38, pp. R199–R222, 2005.

[2] K. Hattori, K. Ito, Y. Soeno, M. Takai, and M. Matsuzaki, “Fabrication of discrete track perpendicular media for high recording density,” *IEEE Trans. Magn.*, vol. 40, no. 4, pp. 2510–2515, Jul. 2004.

[3] Y. Soeno, M. Moriya, K. Ito, K. Hattori, A. Kaizu, T. Aoyama, M. Matsuzaki, and H. Sakai, “Feasibility of discrete track perpendicular media for high track density recording,” *IEEE Trans. Magn.*, vol. 39, no. 4, pp. 1967–1971, Jul. 2003.

[4] D. Wachenschwanz, W. Jiang, E. Roddick, A. Homola, P. Dorsey, B. Harper, D. Treves, and C. Bajorek, “Design of a manufacturable discrete track recording medium,” *IEEE Trans. Magn.*, vol. 41, no. 2, pp. 670–675, Feb. 2005.

[5] X. Che, Y. Tang, H. J. Lee, S. Zhang, K. S. Moon, N. Y. Kim, S. Y. Hong, N. Takahashi, M. T. Moneck, and J. G. Zhu, “Recording performance study of PMR media with patterned tracks,” *IEEE Trans. Magn.*, vol. 43, no. 6, pp. 2292–2294, Jun. 2007.

[6] M. T. Moneck, J. G. Zhu, X. Che, Y. Tang, H. J. Lee, S. Zhang, K. S. Moon, and N. Takahashi, “Fabrication of flyable perpendicular discrete track media,” *IEEE Trans. Magn.*, vol. 43, no. 6, pp. 2127–2129, Jun. 2007.

[7] I. Yamada, J. Matsuo, N. Toyoda, and A. Kirkpatrick, “Materials processing by gas cluster ion beams,” *Mater. Sci. Eng. R*, vol. 34, pp. 231–295, 2001.

[8] S. Kakuta, S. Sasaki, T. Hirano, K. Ueda, T. Seki, S. Ninomiya, M. Hada, and J. Matsuo, “Low damage smoothing of magnetic material films using a gas cluster ion beam,” *Nucl. Instrum. Methods B*, vol. 257, pp. 677–682, 2007.

Manuscript received February 28, 2008. Current version published December 17, 2008. Corresponding author: K. Nagato (e-mail: nagato@hnl.t.u-tokyo.ac.jp).