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Preparation and Magnetic Properties of Ferrite Thin-Film Media

Setsuo YAMAMOTO[†a)], *Regular Member*, **Kei HIRATA**[†], **Hiroki KURISU**[†], **Mitsuru MATSUURA**[†], **Takanori DOI**[††], *and* **Kousaku TAMARI**[††], *Nonmembers*

SUMMARY Employing reactive sputtering using an electron-cyclotron-resonance microwave plasma without oxidation process, high coercivity ferrite thin-films with perpendicular magnetic anisotropy were successfully prepared without NiO underlayer at low substrate temperature. The ferrite thin-film deposited on glass substrate had smooth surface and were composed of small grains. Perpendicular recording was performed on the ferrite thin-film hard disk. The ferrite thin-films with high coercivity could be prepared on flexible film substrates (Polyimide and PET).
key words: *ferrite thin-film, reactive sputtering, perpendicular magnetic recording, recording media*

1. Introduction

We have already proved that a Co-γ Fe_2O_3 spinel ferrite thin-film deposited on a NiO underlayer has feasibility as high density perpendicular magnetic recording media [1]–[5].

The preparation method of the media we have developed is as follows: Using reactive sputtering method with magnetron sputtering apparatus, at first, a (100) oriented NiO underlayer is deposited on a glass substrate. And then, a (200) oriented CoO-Fe_3O_4 thin film is reactive sputter deposited using an Fe-Co alloy target at a substrate temperature of about 200 degrees centigrade. The coercivity of the CoO-Fe_3O_4 thin-film is too low to utilize as recording media. Therefore, the CoO-Fe_3O_4 thin-film is transformed to a Co-γ Fe_2O_3 thin-film with high coercivity over 2000 Oe by the post-oxidation. As the post-oxidation methods, we proposed two methods: One was annealing in the air at 250–300 degrees centigrade for 0.5–2 hours. The other was plasma oxidation using very active oxygen plasma produced by an electron-cyclotron-resonance (ECR) and ionization enhancement using helium. In the plasma oxidation method, the processing temperature was lowered to 150 degrees and processing time was shortened to half to a few minutes. However, from the viewpoint of practical production, simplification in media structure and preparation method is required.

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[†]The authors are with Yamaguchi University, Ube-shi, 755-8611 Japan.
[††]The authors are with Toda Kogyo Corp., Otake-shi, 739-0652 Japan.
a) E-mail: yamamoto@po.cc.yamaguchi-u.ac.jp

In this study, preparation of ferrite thin-films by the sputtering deposition process without post-oxidation process was tried. And the deposition of the ferrite thin-films on the flexible film substrate was carried out aiming at the application to the tape media.

2. Experimental

To prepare the ferrite thin-films, reactive sputtering using ECR sputtering apparatus was performed using an Fe-Co alloy target with a Co content of 6 at. % in the mixture gas of argon and oxygen. Substrate temperature was set in the range of 65 to 150 degrees centigrade. The ferrite thin-films were deposited directly on the substrate without any underlayers. Post-oxidation was not carried out.

Measurement of magnetic properties, surface observation and crystallographic analysis were preformed using a VSM, an AFM and a XRD (Cu-K_α), respectively. In the measurement of recording characteristics, an IND/AMR merged head mounted on a 30% pico-slider was used.

3. Results and Discussions

3.1 Ferrite Thin-Films Deposited on Glass Substrates

Ferrite thin-films were deposited on glass substrates, and the feasibility of application to the hard disk media was investigates. As substrates, two crystallized glasses made by OHARA Corp. (Substrate-A, (TS-10ST) and substrate-B, (TS-CZ)) with a diameter of 2.5 inches disks were used. The thickness of the ferrite thin-films was 70 nm.

M-H hysteresis loops of the ferrite thin-films are shown in Fig. 1. The ferrite thin-film deposited on the substrate-A shows high perpendicular coercivity of 3110 Oe which is 3.2 times as high as its in-plane coercivity of 960 Oe. The squareness in perpendicular direction is 0.56. The perpendicular corercivity of the ferrite film on the substrate-B is rather lower than that on the substrate-A. The perpendicular magnetic anisotropy of the films is supposed to be induced by internal tensile stress in the ferrite thin-film.

Figure 2 shows the X-ray diffraction diagrams for the ferrite thin-films deposited on the substrate-A and

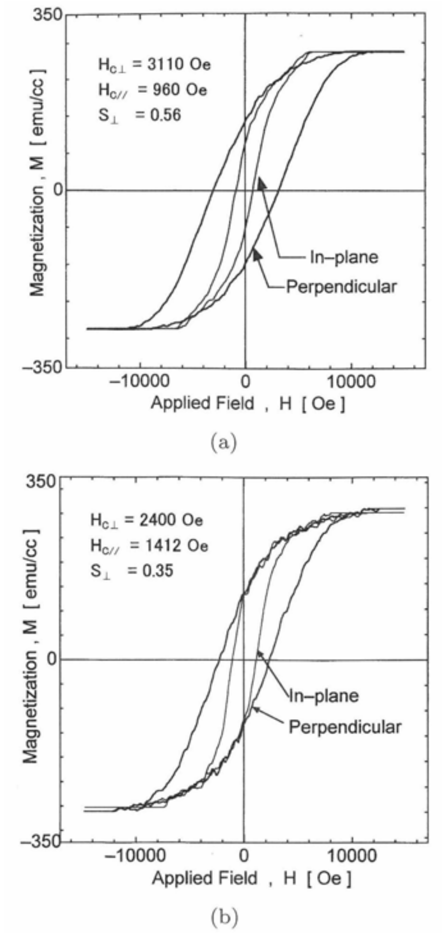

Fig. 1 *M-H* hysteresis loops of ferrite thin-films deposited on glass substrates. (a) On substrate-A. (b) On substrate-B.

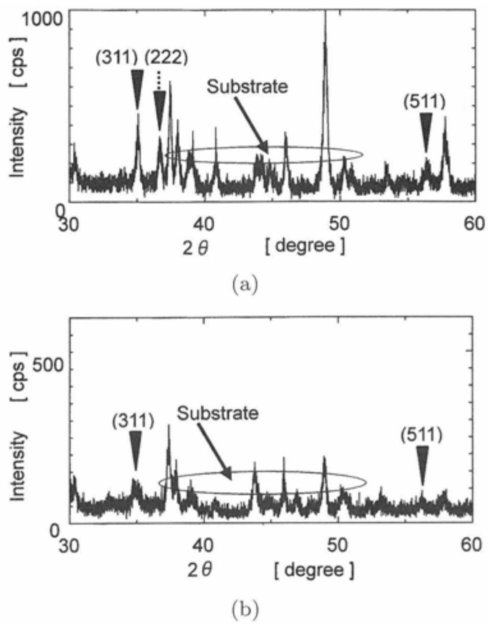

Fig. 2 XRD diagrams of ferrite thin-films deposited on glass substrates. (a) On substrate-A. (b) On substrate-B.

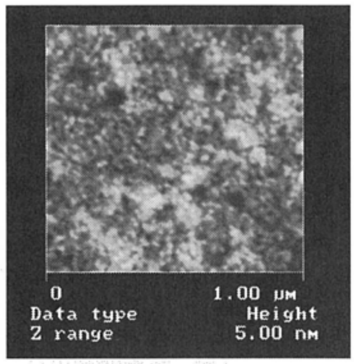

Fig. 3 AFM image of surface of ferrite thin-film deposited on substrate-A.

substrates-B. Both thin-films have spinel ferrite structure, and (311) plane is preferentially oriented. The small difference in crystal orientation is seen in the XRD diagrams. The peak intensity from (311) plane of the ferrite thin-film on the substrate-A is 5 times higher than that on the substrate-B. Although the strong diffraction peaks from (222) and (511) plane are observed for the ferrite thin-film deposited on the substrate-A, the peak from (222) plane is not observed for the film on the substrate-B. From these results, it is concluded that the crystal orientation and crystallinity of ferrite thin-film on the substrate-A is better than that on the substrate-B.

Figure 3 shows the AFM (Atomic force microscopy) image of the surface of the ferrite thin-film deposited on the substrate-A at a substrate temperature lower than 150 degrees centigrade. Average surface roughness (R_a) is 0.37 nm, and the averaged grain diameter is 30.4 nm. Low-temperature sputtering deposition brought such a smooth surface and small grain diameter that is supposed to be preferable to achieve low media noise and small head-to-media spacing.

Recording and reproducing experiment was performed on the ferrite thin-film hard disks.

Figure 4 shows the reproduced waveforms at a recording density of 2.54 kFRPI. (a) is for the ferrite disks using the substrate-A, and (b) is that using the substrate-B. The reproduced waveform was almost same between the two ferrite thin-film hard disks. The reproduced voltage for the ferrite disk using the substrate-A was slightly higher than for the ferrite disk using the substrate-B.

However, judging from the base line shift in the reproduced waveform, perpendicular component of magnetization substantially exists in the ferrite thin-film layer of two ferrite thin-film hard disks.

To conclude, superior magnetic properties, crystallographic properties and recording characteristics were achieved in the ferrite thin-film disk using the substrate-A as compared with that using the substrate-B.

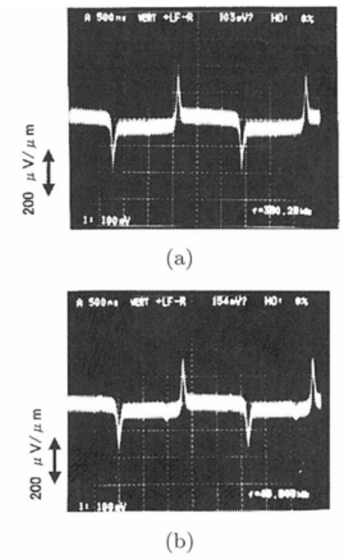

Fig. 4 Reproduced waveforms at 2.54 kFRPI for ferrite thin-film hard disks. (a) On substrate-A. (b) On substrate-B.

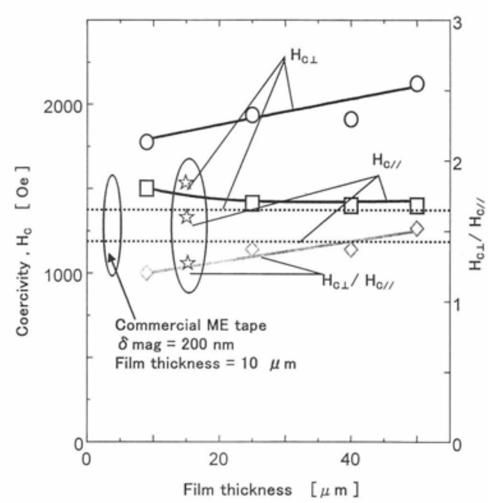

Fig. 5 Substrate thickness dependence of magnetic properties of ferrite thin-films. Stars are for ferrite thin-film deposited on 14 microns thick PET film substrate. Dotted lines are for commercial ME tape. Others are for ferrite thin-films deposited on polyimide film substrate.

3.2 Ferrite Thin-Films Deposited on Flexible Substrates

The 120 nm thick ferrite thin-films were deposited on several kinds of organic flexible film substrates at the lower temperature, and the possibility of application to tape media was investigated. As substrates, polyimide film with a various thickness (UBE Co., Ltd: UPILEX) and PET (polyethylene terephthalate) film were used.

Substrate thickness dependence of perpendicular and in-plane coercivity and perpendicular to in-plane coercivity ratio of the ferrite thin-films deposited on the PET film substrate with a thickness of 14 μm and polyimide film substrates with a various thickness of 9 to 50 μm are shown in Fig. 5. The data for the ferrite thin-film deposited on 14 μm thick PET film substrate are shown as star symbols. The magnetic properties of the commercial ME tape for a VTR is also shown as a reference. All of the ferrite thin-film samples deposited on polyimide film substrate show the high coercivity more than 1700 Oe. The perpendicular coercivity and the perpendicular to in-plane coercivity ratio gradually decrease with decreasing film substrate thickness. For the ferrite thin-film sample deposited on the PET film substrate, the perpendicular and in-plane coercivities are 1680 Oe and 1430 Oe, respectively. All the ferrite thin-film samples show higher perpendicular coercivity than that of the commercial ME tape.

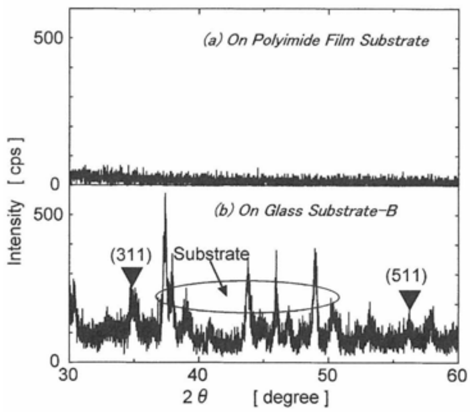

Fig. 6 XRD diagrams of ferrite thin film deposited on flexible film substrate and the glass substrate-B.

Figure 6 shows an example of X-ray diffraction diagrams for the ferrite thin-film deposited on the flexible film and the glass substrate-B. For the ferrite thin-film deposited on the glass substrate-B, diffraction peaks from spinel ferrite structure are observed. However, for the ferrite thin-films on polyimide film substrate, XRD analysis shows that the film is amorphous like. The ferrite thin-films on the PET substrate is also amorphous like.

Further study is needed to clarify the origin of high perpendicular coercivity of ferrite thin-films on flexible film substrates in spite of their amorphous like structure.

Substrate temperature dependence of magnetic properties of the ferrite thin-films on the polyimide film substrate (50 μm) was examined. In the temperature range from 60 degrees centigrade to 150 degrees centigrade, remarkable dependence of the coercivity and saturation magnetization was not observed.

4. Conclusions

In conclusion, the following results were obtained in this study.

(1) Using reactive ECR sputtering without post annealing process, the high coercivity ferrite thin-films with perpendicular magnetic anisotropy were prepared without NiO underlayer.
(2) The ferrite thin-films deposited on the glass substrate show very smooth surface (R_a of 0.37 nm) and small grain diameter.
(3) The reproduced waveform suggested that perpendicular magnetization component existed in the ferrite thin-film on glass substrate.
(4) High coercivity as high as 2000 Oe was achieved on the ferrite thin-films deposited on flexible film media (polyimide and PET films).

In this study, the ferrite thin-film media structure and the fabrication process were simplified considerably, and this is of benefit to their mass production. Furthermore, the feasibility of ferrite thin-film tape media was proved.

References

[1] K. Tamari, T. Doi, and N. Horiishi, "Magnetic and magneto-optical properties of the Co-γ Fe_2O_3 perpendicular magnetic films," Appl. Phys. Lett., vol.63, no.23, pp.3227–3229, 1993.
[2] T. Doi and K. Tamari, "Preparation and the magnetic properties of Co-γ Fe_2O_3 perpendicular magnetic films on NiO underlayer," J. Appl. Phys., vol.79, no.8, pp.4887–4889, 1996.
[3] S. Yamamoto, T. Andou, H. Kurisu, M. Matsuura, T. Doi, and K. Tamari, "Recording characteristics of Co-γ Fe_2O_3 perpendicular magnetic recording media," J. Appl. Phys., vol.79, no.8, pp.4884–4886, 1996.
[4] S. Yamamoto, T. Santoki, H. Kurisu, M. Matsuura, J. Kojima, K. Nakata, Y. Kakihara, T. Doi, and K. Tamari, "Co-γ Fe_2O_3 thin film disks fabricated by plasma oxidization," J. Magn. Soci. Jpn., vol.22, no.S3, pp.21–25, 1998.
[5] S. Yamamoto, H. Kurisu, M. Matsuura, T. Doi, and K. Tamari, "Co-γ Fe_2O_3/NiO thin-film media for perpendicular and longitudinal magnetic recording," J. Magn. Soci. Jpn., vol.23, no.5, pp.1739–1745, 1999.

Setsuo Yamamoto received the B.S. degree in physics, the M.S. degree and Ph.D. degree in applied physics from Tohoku University in 1980, 1982 and 1985, respectively. In 1985, he joined Tohoku University as a research associate of Research Institute of Electrical Communication, where he engaged in research and development on perpendicular magnetic recording. Since 1988, he has been an associate professor of department of Advanced Materials Science and Engineering, Faculty of Engineering, Yamaguchi University. His current research interest includes R&D on magnetic materials, micro magnetic devices, and high density information storage technology. Dr. Yamamoto is a member of IEEE Magnetics Society, the Institute of Electrical Engineering of Japan, the Institute of Image Information and Television Engineers, the Magnetics Society of Japan, the Materials Research Society of Japan (MRS-J), the Japan Society of Powder and Powder Metallurgy, and Committee 144 (Magnetic Recording) of the Japan Society for the Promotion of Science.

Kei Hirata received B.E. degree in Advanced Materials Science and Engineering from Yamaguchi University, Japan in 2000. He is now on the graduate school of Yamaguchi University where he engages in research on magnetic recording media for perpendicular recording.

Hiroki Kurisu received the B.Ed. in Physics from Nara University of Education in 1987 and D.Sc. from Osaka City University in 1993. Shortly after that, he joined Faculty of Engineering, Yamaguchi University as a Research Associate. His current interest is Electronic and Optical Properties of Condensed Matter, especially Dynamical Process in Mesoscopic Materials.

Mitsuru Matsuura received the D.Sc. from Tohoku University in 1970. Then he joined Department of Physics, Faculty of Science, Waterloo University in Canada, and also joined National Research Council of Canada as a research fellow. He was an associate professor in Faculty of Engineering, Yamaguchi University in 1975. He's been Professor in Faculty of Engineering, Yamaguchi University since 1981. He's majored in Quantum Theory of Condensed Matter, Electronic Properties of Materials, especially in Semiconductors.

Takanori Doi received the M.S. degree from Hiroshima University in 1987. He received Ph.D. degree in Materials Science and Engineering from Yamaguchi University in 1998. He joined Toda Kogyo Corporation in 1987 and worked on development of ferrite powder, organic nonlinear optical materials. He is now engaging in the research and development of thin-film magnetic recording media.

Kousaku Tamari received Ph.D. degree from Hiroshima University in 1988. He joined Toda Kogyo Corporation in 1988 and has been engaging on research and development of magnetic powder materials and thin-film media for high density information storage.