Crystal orientation improvement by carbon addition for FePt-oxide granular films for heat assisted magnetic recording media

Kim Kong Tham[1], Ryosuke Kushibiki[1], Daiki Miyazaki[1], Shin Saito[2]

[1]TANAKA PRECIOUS METAL TECHNOLOGIES Co., Ltd, Tsukuba 300-4247, Japan, tham@ml.tanaka.co.jp
[2] Department of Electronic Engineering, Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan

Investigation of magnetic properties and nanostructure of FePt granular films with oxide grain boundary material (GBM) substituted by carbon is reported. Similar tendency to FePt-oxide granular films, saturation magnetization in FePt-oxide-carbon granular films also varies almost linearly against volume averaged melting point (T_m^{ave}) of the GBM. The values of perpendicular magnetic anisotropy and degree of order of $L1_0$-FePt phase for all FePt-oxide-carbon granular films varies to be closer to those of FePt-carbon granular films with values larger than 9×10^6 erg/cm^3 and 0.75, respectively, when oxide is partially substituted with carbon. Furthermore, the amount of magnetic grain with *c*-axis parallel to the film plane in FePt-oxide-carbon granular films is significantly reduced than that of FePt-oxide granular films.

Index Terms— **FePt-oxide-carbon, granular film, melting point, c-axis parallel to the film plane, grain size, heat assisted magnetic recording.**

I. Introduction

HEAT ASSISTED MAGNETIC RECORDING (HAMR) is expected to replace perpendicular magnetic recording (PMR) for the next generation magnetic recording technology. For the HAMR media, $L1_0$ type FePt thin film is an attractive material due to its high magnetocrystalline anisotropy of 5×10^7 erg/cm^3 at room temperature. In-order-to realize FePt thin film as the HAMR medium, it is necessary to solve some issues, such as the formation of a granular structure with fine columnar magnetic grains, high c-axis orientation, and high degree of order. Regarding the achievement of these requirements, many studies of adding grain boundary materials (GBMs), such as C [1-2], TiO_2 [3], Ta_2O_5 [4], GeO_2 [5], Al_2O_3 [6], Nb_2O_5 [7], Cr_2O_3 [8], SiO_2 [9], and B_2O_3 [10] into the FePt thin film to isolate the magnetic grains and reduce intergranular exchange coupling have been conducted. According to our previous report, saturation magnetization (M_s) of the granular film depends on the melting point of the GBMs that M_s of the granular film shows the degree of phase separation between metal magnetic grains and amorphous non-magnetic GBM [10]. The granular films with C GBM show the characteristic of relatively low M_s, which suggests insufficient phase separation and high degree of grain-to-grain separation. When granular films with C and oxide GBMs were compared, it was found that the granular films with some oxides GBM show higher degree of phase separation than that of with C GBM. However, there is a drawback in nanostructure of the granular films with oxide GBM, which has larger amount of in-plane component compared to the films with C GBM. Therefore, to promote the grains isolation while maintaining high degree of phase separation and less in-plane component of FePt granular film with oxide GBM, we have carried out an experiment of partially substituting oxide with C GBM in granular films and evaluated the magnetic properties and nanostructure.

II. Experiments

All samples were prepared using RF/DC magnetron sputtering (Canon Anelva C3010-P7-UHV; 7-chamber configuration with single-side film fabrication, each process can be carried out in an independent chamber separated with gate valve). The in-line sputtering equipment is almost the same model as that for the mass production of PMR media. The stacking structure of the samples is amorphous glass substrate (0.635 mm thick)/ $Co_{60}W_{40}$ (Ar gas pressure: 0.6 Pa, film thickness: 80 nm, substrate temperature: RT)/ MgO (4 Pa, 5 nm, RT)/ Magnetic layer (8 Pa, 5 nm, 550 °C)/C (0.6 Pa, 7 nm, RT). The magnetic layer was deposited at sputtering power of 0.5 W/cm^2. $Fe_{50}Pt_{50}$–15vol% oxide–15vol% C sintered targets were used for the magnetic layer. For comparison, the samples prepared with $Fe_{50}Pt_{50}$–30vol% oxide sintered targets were also fabricated. *M-H* loops were measured by using a vibrating sample magnetometer equipped with a SQUID detector (Quantum Design, MPMS3) at the maximum applied field of 70 kOe. Torque curves were measured by using a physical property measurement system with a torque magnetometer option (Quantum Design, PPMS) with the maximum applied field of 90 kOe [11]. Crystal structure was examined using out-of-plane and in-plane X-ray diffraction (XRD) measurements with Cu Kα radiation at wavelength of 1.542 Å (Rigaku, SmartLab; 9 kW/ parallel beam configuration/ 2D detector). Nanostructure of the films was observed by transmission electron microscopy (TEM) with an acceleration voltage of 300 kV.

III. Results And Discussion

Fig. 1 shows dependence of (a) M_s and (b) $K_{u\perp}$ of FePt-oxide-C granular films on the volume averaged melting point (T_m^{ave}). M_s and $K_{u\perp}$ are derived from the gradient plot of total magnetization and perpendicular magnetic anisotropy of the granular film against the film thickness from 2 to 10 nm, respectively. Dotted lines in the figures represent the values of

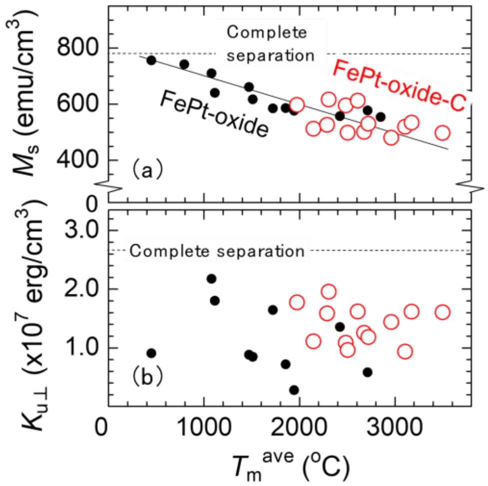

Fig. 1 Dependence of (a) M_s and (b) $K_{u\perp}$ of FePt-oxide-C granular films on the volume averaged melting point (T_m^{ave}).

M_s and $K_{u\perp}$ of complete separation calculated from magnetic parameters of FePt films described in the previous results [12], assuming 70 vol% FePt and 30 vol% GBMs are completely separated, where there is no element decomposes from the GBMs and dissolves into the FePt magnetic grains. Here, Tmave is the volume averaged melting point of oxide and carbon GBMs. M_s and $K_{u\perp}$ of granular films of both oxide-C and oxide GBMs are still lower compared to those of granular films with complete separation. M_s of FePt-oxide-C granular films shows similar tendency with that of FePt-oxide granular films which varies almost linearly against T_m^{ave} [10]. When T_m^{ave} is varied from around 2000 to 3500 °C, M_s of FePt-oxide-C granular films changes from around 600 to 530 emu/cm^3. On the other hand, there is no strong correlation observed between $K_{u\perp}$ and T_m^{ave}. The value of $K_{u\perp}$ for all FePt-oxide granular films is enhanced to be larger than 9×10^6 erg/cm^3 when oxide is partially substituted by C.

Fig. 2 shows in-plane XRD profiles for (a) FePt-oxide-C and (b) FePt-oxide granular films. For both granular films, at Bragg angles of around 33°, 47°, and 69°, the (110), (200), and (220) diffractions of the $L1_0$-FePt phase are observed, respectively, which reveals that the FePt magnetic grains have *c*-plane sheet texture. Focusing at the Bragg angle of around 24°, the integral intensity of (001) diffraction of the $L1_0$-FePt phase in the FePt-oxide-C granular films is smaller compared to that of FePt-oxide granular films, which indicates that FePt-oxide-C granular films has less magnetic grains with *c*-axis parallel to the film plane than that of FePt-oxide granular films.

IV. Conclusion

The combination of oxide with C is effective to promote the grain isolation, while maintaining high degree of phase separation and small amount of in-plane component.

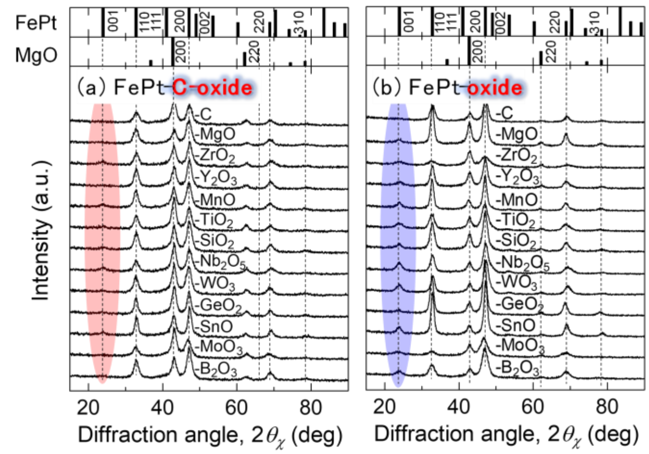

Fig. 2 In-plane XRD profiles for (a) FePt-oxide-C and (b) FePt-oxide granular films.

References

[1] J. S. Chen, B. C. Lim, J. F. Hu, B. Liu, G. M. Chow, and G. Ju, *Appl. Phys. Lett.*, **91**, 132506 (2007).

[2] A. Perumal, Y. K. Takahashi, and K. Hono, *J. Appl. Phys.*, **105**, 07B732 (2009).

[3] Y. F. Ding, J. S. Chen, B. C. Lim, J. F. Hu, B. Liu, and G. Ju, *Appl. Phys. Lett.*, **93**, 032506 (2008)..

[4] B. C. Lim, J. S. Chen, J. F. Hu, P. W. Lwin, Y. F. Ding, K. M. Cher, and B. Liu, *J. Appl. Phys.*, **105**, 07A730 (2009).

[5] T. Ono, T. Moriya, M. Hatayama, K. Tsumura, N. Kikuchi, S. Okamoto, O. Kitakami, and T. Shimatsu, *Appl. Phys. Lett.*, **110**, 022402 (2017).

[6] J. Bai, Z. Yang, F. Wei, M. Matsumoto, and A. Morisako, *J. Magn. Magn. Mater.*, **257**, 132 (2003).

[7] T. Shiroyama, T. Abe, Y. Takahashi, and K. Hono, *IEEE Trans. Magn.*, **49**, 3616 (2013).

[8] T. Shiroyama, B. S. D. Ch. S. Varaprasad, Y. K. Takahashi, and K. Hono, *IEEE Trans. Magn.*, **50**, 3202404 (2014).

[9] E. Yang and D. E. Laughlin, *J. Appl. Phys.*, **104**, 023904 (2008).

[10] T. Saito, K. K. Tham, R. Kushibiki, T. Ogawa, and S. Saito, *Jpn. J. Appl. Phys.*, **59**, 045501 (2020).

[11] T. Saito, K. K. Tham, R. Kushibiki, T. Ogawa, and S. Saito, *IEEE Trans. Magn.*, **57**, 3200505 (2021).

[12] R. Kushibiki, K. K. Tham, S. Hinata, and S. Saito, *AIP Adv.*, **8**, 056512 (2017).