High-density $L1_0$-FePt grains on an electrically conductive (Mg,Ti)O underlayer for HAMR media.

A. R. Dilipan[1,2], H. Sepehri-Amin[1,2], and I. Suzuki[1], Y. K. Takahashi[1,2,3]

[1]National Institute for Materials Science, Tsukuba 305-0047, Japan.
[2]Graduate School of Science and Technology, University of Tsukuba, Tsukuba 305-8577, Japan.
[3]Research Institute of Electrical Communications, Tohoku University, Sendai, Japan.

Achieving high-density recording media composed of small, columnar and well separated $L1_0$-FePt grain is essential for high storage capacity heat-assisted magnetic recording (HAMR) media. A suitable segregant and an efficient underlayer is utmost important factor for obtaining a high-density recording media. We investigated the growth of $L1_0$-FePt granular films on with C and BN segregants on MgO substrate with and without a (Mg,Ti)O underlayer. FePt-C grown on (Mg,Ti)O shows larger grain size of ~11.1 nm with lower grain-density 4.8 Tgrains/in^2, whereas FePt-BN show smaller grains of ~6.6 nm with about two-fold increase in grain density of 9.0 Tgrains/in^2. Microstructural analysis shows the enrichment of Ti and N at interface of FePt-BN and (Mg,Ti)O, resulting in smaller and columnar grains. These findings elucidate that the FePt-BN is an optimal choice for achieving fine-grained and high-density recording media on electrically conductive (Mg,Ti)O underlayer.

Index Terms— $L1_0$-FePt, underlayer, segregant, high-density recording media, HAMR

I. Introduction

Heat-assisted magnetic recording (HAMR) is a promising technology that has enabled large data storage capacity or areal recording density (ARD) of hard disk drives beyond 4 Tb/in^2 [1]. Chemically ordered $L1_0$ FePt has been used as a HAMR media due to their high magnetic anisotropy constant (Ku) of 6.6 MJ/m^3 [2]. An ideal microstructure with grain size <4.3 nm, a pitch distance (center-to-center distance) < 5.3 nm, and columnar grains with an aspect ratio (h/D) > 1.5, along with high (001) texture, is necessary to achieve high ARD [3]. The microstructure of the FePt-X media is primely controlled by segreant materials, underlayer and sputtering condition used for fabricating the media. Here 'X' is the segregant that act as an intergranular phase, which helps in granular microstructure and isolation of grains. Among various segregants used [4], carbon shows promising results in achieving small and well isolated grains, when deposited on MgO underlayer or substrate. However, they form spherical-shaped FePt grains and does not result in columnar grains. Recently, boron nitride as a segregant has been demonstrated to show smaller grains when compared to FePt-C [5]. In the aspect of underlayer, MgO as a substrate and as an underlayer has proven to show epitaxial growth of FePt-X grains. However, the MgO underlayer requires a longer deposition time due to their electrically insulating nature and the need for RF sputtering. An alternate is to use electrically conductive $(MgTi)_xO$ with a crystal structure and lattice parameters comparable to MgO. In previous studies, FePt-C deposited in $(MgTi)_xO$ always resulted in larger grains with irregular grain morphology [6]. In the present work, we investigated the microstructure, interface, and magnetic properties of epitaxially grown FePt-X (X= C and BN) on MgO substrate and $(Mg,Ti)_xO$ underlayer.

II. Experimental

6 nm-thick FePt-C 40 vol.% and FePt-BN 25 vol.% (hereinafter, FePt-C and FePt-BN) layers were deposited individually on MgO substrate and (Mg,Ti)O underlayer (MTO) using an ultra-high vacuum co-sputtering system with a base pressure of ~10^{-7} Pa. The MTO underlayer was grown on the MgO substrate to obtain epitaxial growth of the FePt film. Before deposition of the films, the MgO (001) single crystalline substrate was prepared by cleaning with ethanol and acetone, and thermally flushed at 650°C for 1 h. MTO underlayer of 5 nm thickness was deposited on a single crystalline MgO (001) substrate at 600°C.

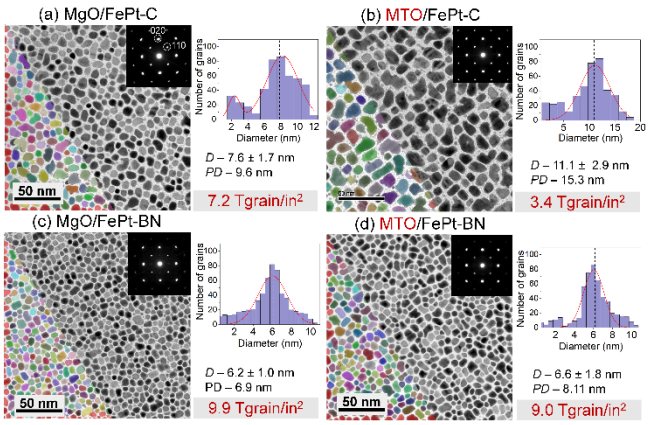

Fig. 1. Plane-view BF-TEM images, overlay color maps, grain size distribution histogram, and their SAED pattern (inset) of (a) MgO/FePt-C, (b) MTO/FePt-C (c) MgO/FePt-BN and, (d) MTO/FePt-BN.

The best deposition parameters were adopted for fabricating FePt-C and FePt-BN layers. The FePt-C 40 vol.% layer was deposited by co-sputtering FePt and C targets separately at the substrate temperature of 600°C, whereas the FePt-BN was sputtered with a composite target of FePt-25 vol.% BN with the assistance of Ar + N_2 gas flow at 700°C. Finally, a carbon capping layer of 5 nm was deposited at room temperature to avoid surface damage to the FePt-C and FePt-BN media layers. The volume fraction of FePt and segregants in the media layer was estimated using the pre-measured sputtering deposition rate. Transmission electron microscopy (TEM) coupled with energy

dispersive X-ray spectroscopy (EDS) was performed using TITAN G2 80-200 TEM and Spectra Ultra S/TEM 30-300 (Thermo Fisher Scientific).

III. Plane-view Microstructural Analysis

Figure 1 shows the plane-view bright field (BF)-TEM images, overlay color map and grain size distribution histograms of all the samples. The MgO/FePt-C (Figure 1a) shows an average grain size (D) of 7.6 ± 1.7 nm, with a pitch distance (PD) of 9.6 nm with a relatively high grain density of 7.2 Tgrain/in^2. Whereas, the MTO/FePt-C (Figure 1b) shows larger grains of of 11.1 ± 2.9 nm, and PD of 15.3 nm, resulting in a decreased grain density of 4.8 Tgrain/in^2. This observation aligns with the earlier studies on the FePt-C grown on polycrystalline substrates as reported elsewhere [6]. The larger grain size and agglomerated microstructure in FePt-C on MTO can be due to the higher surface free energy (SFE) of the MTO underlayer. The high SFE increases the wettability, which induces grain growth responsible for coarser FePt grains on MTO. The microstructure of FePt-BN on the MTO underlayer is retained with smaller and well-separated grains, similar to those grown on MgO (Figure 1c and 1d). The overall grain size of FePt-BN irrespective of the underlayer is smaller than that of FePt-C, with a D value of 6.2 ± 1.0 nm for MgO/FePt-BN and 6.6 ± 1.8 nm for MTO/FePt-BN. The smaller grain size of FePt-BN demonstrates a high grain density exceeding 9.0 Tgrain/in^2, significantly higher than FePt-C films. Although MTO possesses higher surface free energy than MgO, the use of BN segregant is advantageous in mitigating the coarsening of the grains. The reduced grain size and high grain density in FePt-BN films grown on MTO demonstrate the efficacy of this combination, which can be developed as an optimal recording media.

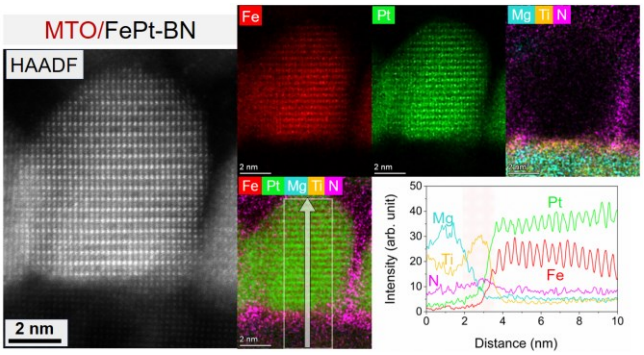

Fig. 2. Cross-sectional HAADF-STEM along with the STEM-EDS elemental maps and composition line profile of constituent elements of MTO/FePt-BN.

IV. Cross-sectional Microstructural Analysis

In order to understand the contributions to the smaller grains and growth mechanism, a detailed cross-sectional elemental analysis is conducted. Figure 2 shows the High-angle annular dark field (HAADF) Scanning-TEM images, corresponding the EDS elemental maps, and line profile analysis of the single grain corresponding to MTO/FePt-BN. From the HAADF-STEM image, a periodic dark and bright contrast is observed, representing a high $L1_0$ ordering of FePt grain. According to the EDS maps and corresponding composition line profiles, the segregation of Ti on the surface of MTO is observed with no diffusion of Ti into the FePt grains. Interestingly, N encapsulates the FePt-grains, with a noticeable N enrichment at the MTO and FePt-BN interface. This could be attributed to the reactive sputtering of FePt-BN media layer, where a mixture of Ar+N_2 was used as a sputtering gas. Due to the nitrogen flow during the main layer deposition, there is a high possibility of nitriding at the surface of the MTO underlayer. As a result, the composition of the MTO underlayer at its surface is altered to be in the combination of (Ti,N)-rich composition, which is favorable for smaller grain size with high grain density.

V. Conclusion

In conclusion, this study presents a comprehensive investigation of the microstructure, magnetic properties, and interface of the FePt-C and FePt-BN granular films deposited on MgO substrate and (Mg,Ti)O (MTO) underlayer. The plane-view microstructural analysis revealed that the MgO/FePt-C film have smaller grains with high grain density, whereas the MTO/FePt-C film displayed larger grains with coarsened grains with low grain density. Interestingly, FePt-BN on MTO show smaller grain size with two-fold higher grain density compared to MTO/FePt-C. Overall, incorporating BN as a segregant for $L1_0$ FePt, one can easily achieve a desirable microstructure with smaller grains and high grain density on an electrically conductive MTO underlayers, suitable for high storage capacity HAMR media.

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