Optimized Multi-Level Heat Assisted Magnetic Recording Media with Mo spacer layer for High - Capacity Data Storage

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Multi-level Heat Assisted Magnetic Recording (HAMR) is a novel approach for HAMR technology for increasing the storage capacity of Hard Disc Drives (HDDs) with an aim to reach 4Tbit/in^2 areal recording density. This concept was first realized with dual layer FePt media with Ru as the spacer layer material. In this work, we optimize the microstructure and magnetic properties of dual layer FePt media with Molybdenum spacer layer material, thereby understanding the parameters to be considered while choosing a spacer layer material for 3D-HAMR media. The Mo spacer layer showed novel flat interface which is beneficial for the top layer ordered growth. This flatness effect was investigated and realized that both lattice misfits' strain at the interface between the two materials (FePt and Mo) and thermal energy was accountable for such rarity. Further refinement was also demonstrated by inserting an insertion layer (MgO or MgTiON) between spacer layer and top layer such that the diffusion of spacer layer material to the top FePt could be reduced thus enhancing the ordering of the top layer.

***Index Terms*—Multi level Heat Assisted Magnetic Recording, HAMR, areal recording density, dual layer FePt, 3D-HAMR, spacer layer, insertion layer, tri-layer.**

I. Introduction

The creation and usage of new digital information is taking place every moment, leading to the need for more reliable yet affordable storage solutions. An enhancement in the data storage density of Hard Disc Drives (HDD), which serves as the major storage unit in data centers, is paramount [1]. The conventional perpendicular magnetic recording (PMR) system has a limitation of maximum 1Tbit/in^2. Therefore, a new technology of magnetic recording with assistance of external energy such as heat [2] or microwave was proposed [3]. Thus, Heat Assisted magnetic recording was developed with $L1_0$ FePt, a high magneto crystalline anisotropy ferromagnetic material [4]. To attain an areal density of 4Tbit/in^2, an ideal grain size of 4.3 nm with a good $L1_0$ ordering is essential [5,7]. However, even with various non-magnetic matrixes like C, h-BN, the maximum reduction in grain size was up to 5 nm [6,7]. For further enhancement in magnetic recording density, instead of stacking a greater number of platters in one HDD and thereby increasing energy consumption, a cleantech approach of increasing the recording layers on the same platter is put forward. This concept which relies on HAMR technology is known as multi-level HAMR media, in which two magnetic recording layers are separated by a non-magnetic breaking layer, also known as spacer layer. The first experimental realization of 3D-HAMR was FePt/Ru/FePt tri- layer, however, this media faced some challenges like the presence of in-plane variants, lack of top layer $L1_0$ ordering at the initial growth of around 1nm and presence of few disorders at the top grain [8]. These issues could be due to less lattice misfit strain, as large misfit induces misfit strain that can enhance ordering and [001] texture. Thus, Molybdenum, a non-magnetic material with a lattice misfit of 18.4% and very less diffusion chances by checking the phase diagram of Fe-Mo and Pt-Mo, was considered in this work as spacer layer material.

II. Methodology

All the samples were synthesized by ultra-high vacuum magnetron sputtering on a single crystalline (001) MgO substrate at a base pressure of around 10^{-7}Pa. The tri-layer was composed of FePt-40vol%C/Mo-40vol%C/FePt-40vol%C with a 5nm carbon coating at room temperature under Ar pressure of 0.478Pa. Here, molybdenum acts as a breaking layer between the ferromagnetic FePt layers. The structural analysis was carried out by the Rigaku Smart Lab X-Ray Diffraction (XRD) machine and the degree of $L1_0$ ordering (or order parameter, S) was calculated from the integrated intensities of the superlattice (I_{001}) and fundamental peaks (I_{002}), using the equation, $S = \alpha (I_{001}/ I_{002})^{1/2}$ and $\alpha = 0.85$. The microstructure of the films was studied by Titan G2 80- 200 transmission electron microscopy (TEM) in both in-plane and cross-sectional view. The samples were prepared by polishing and chemical etching for the in-plane view. The average grain diameter and areal density were determined using deep learning models [9]. By lift-out technique with focused ion beam (FEI Helios Nanolab 650), the ultra-thin cross-sectional samples were fabricated. In order to understand the composition of the films, energy dispersive X- ray spectroscopy (EDS) was performed with FEI Super-X EDX detector and analyzed by velox software and the magnetic measurements were carried out by thin film MPMS3 (Quantum Design) up to a field of 7T.

III. Results and Discussions

1.Microstructure and magnetic properties of FePt-C /Mo-C/FePt-C

After the initial optimization, a film of FePt-40vol%C (3.5nm, 600°C)/ Mo-40vol%C (2nm, 600°C)/ FePt-40vol%C (3.5nm, 600°C) was synthesized. Having a very high order parameter of 0.96 and the coercive field of 2.05T, this sample shows not only granular microstructure with a grain diameter of 8.6nm, but the cross-sectional TEM view shows a flatness at the interface between the bottom and spacer layer. Flattening at the interface can promote a good growth of spacer layer and ordered top layer over it. In this sample, both top and bottom layer shows $L1_0$ ordering, however from the EDS analysis it is found that Mo is getting diffused into the top layer around 1nm.

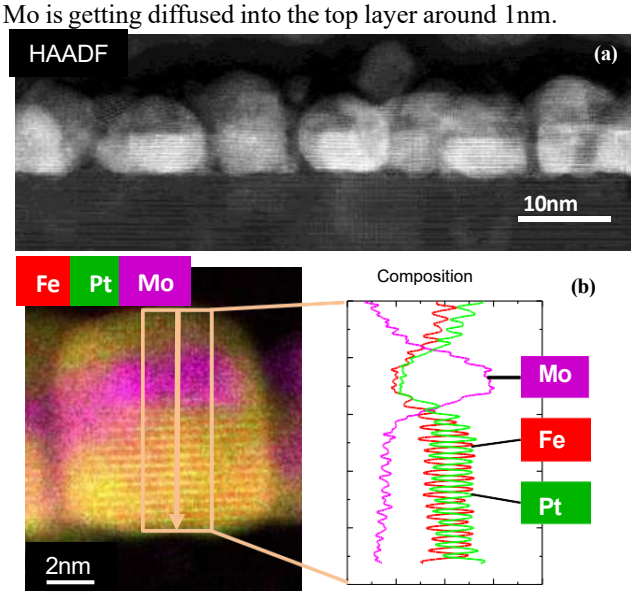

Fig 1. (a) HAADF image, and (b) EDS map with line scan of FePt-40vol%C (3.5nm,600°C)/ Mo-40vol%C (2nm, 600°C)/ FePt-40vol%C(3.5nm,600°C)

2.Flatness at the interface of FePt and Mo

The flattening at the interface was investigated, by preparing four different films as follows:

Sample A: FePt-40vol%C (3.5nm, 600°C)
Sample B: FePt-40vol%C (3.5nm,600°C)/ Mo-40vol%C (2nm, RT)
Sample C: FePt-40vol%C (3.5nm, 600°C)/ Mo-40vol%C (2nm, 500°C)
Sample D: FePt-40vol%C (3.5nm,600°C)/ Mo-40vol%C (2nm, RT)/ 500°C annealed.

The sample A FePt-40vol%C deposited at 600°C on MgO substrate with carbon segregant. It provided good $L1_0$ ordering and a granular microstructure with a spherical cross-sectional structure. The sample B consists of Mo deposited at room temperature on top of FePt grains. The motivation behind this deposition was to check if the lattice misfit between FePt and Mo alone could be responsible for the flattening of the interface. However, from the cross-sectional image of this sample, the flattening at the interface was not evident. Further, sample C was deposited with Mo at an elevated temperature of 500°C to understand the role of temperature along with lattice misfit strain. As expected, the grains had flattening at the interface, but the Mo at high temperature diffuses into the FePt grains slightly, thereby reducing the ordering. Later, the final sample, D was prepared with an aim to retain flatness while reducing the diffusion such that ordering will be reserved. Here, on FePt-40vol%C at 600°C, Mo was deposited at room temperature and the as-deposited film was annealed at 500°C for 5 minutes. Surprisingly, in this film flattening at the interface without any diffusion of spacer layer material into FePt grain was visible. Thus, concluded that not only the lattice mismatch strain, but thermal energy is also responsible for the flatness at the interface. The HAADF view of all samples is given in fig. 2.

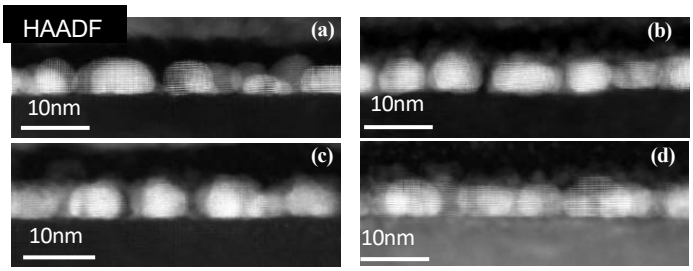

Fig. 2. HAADF image of (1) FePt-40vol%C (3.5nm,600°C), (2) FePt-40vol%C(3.5nm,600°C)/ Mo-40vol%C (2nm, RT), (3) FePt-40vol%C (3.5nm,600°C)/Mo-40vol%C (2nm,500°C), and (4) FePt-40vol%C (3.5nm,600°C)/ Mo- 40vol%C (2nm, RT)/ 500°C annealed.

IV. Conclusion

To improve the recording capacity of HDD, 3D-HAMR with Mo spacer layer has been studied. Interesting observation of flatness at the interface was investigated and concluded that large lattice misfit and thermal energy was responsible for this.

V. Acknowledgement

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