ADVANCED STORAGE TECHNOLOGY CONSORTIUM
RESEARCH PROPOSAL

Development of FePt based HAMR media

April 30, 2011

Abstract
We propose the development of nanogranular perpendicular recording media for heat assisted magnetic recording (HAMR) for 2 Tb/in\(^2\) areal density. Following our successful work on the development of (FePt)Ag-C HAMR recording media on thermally oxidized Si substrates, we will optimize the microstructure of the FePt based granular films further so that they can be examined with both static and spin stand tests. Technical issues to be covered include perfect (001) alignment of 4 nm L1\(_0\)-FePt particles with less than 10\% size distribution on 1.8" glass disks with coercivity higher than 22 kOe using a substrate temperature below 600\(^\circ\)C. After optimizing the composition of FePtX films using co-sputtering process, we will try to achieve the same microstructure using a single alloy target. We will explore appropriate underlayers other than MgO that can be processed by DC sputtering. The effect of metallic underlayer as heat sink on recording density will also be examined experimentally.

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Area of Research Interest for ASTC
HAMR No.2: Fabrication and characterization of small grain size HAMR media
HAMR No.3: Develop high Hk recording media films
Complete description of the research matter and its connection with ASTC stated goals

$L_{10}$ ordered FePt granular thin films are considered as the most promising candidates for heat assisted magnetic recording (HAMR) media with the recording density exceeding 1 Tb/in$^2$. Because of the high magnetocrystalline anisotropy ($K_u \approx 7 \times 10^7$ erg/cc) of the $L_{10}$ FePt phase, the particle size of as small as 4 nm is expected to be stable for permanent recording. However, for the practical application of FePt films as HAMR media, the thin film structure has to be optimized in the following four aspects:

1) excellent c-axis alignment normal to the film plane
2) grain size of less than 6 nm with a narrow size distribution
3) coercivity higher than 22 kOe and small saturation field distribution (SFD)
4) processability of the above granular structure using the existing media manufacturing facilities, i.e. all layers must be sputter deposited with DC at substrate temperature below 600°C.

In 2008, we reported successful processing of FePt-C granular films with unprecedentedly uniform particle isolation and size distribution with a strong perpendicular anisotropy using a (001)-textured MgO interlayer on a thermally oxidized silicon substrate [A. Perumal, Y. K. Takahashi, and K. Hono, APEX 1, 101301 (2008)]. Subsequently, we reported perpendicular FePt-C granular films deposited at 450°C with $H_c=12$ kOe [A. Perumal, Y. K. Takahashi and K. Hono, JAP 105, 07B732 (2009)]. In order to enhance the $L_{10}$ ordering of the FePt particles, we alloyed Ag to the FePt-C granular films and succeeded in attaining $H_c=38$ kOe at a substrate temperature of 450°C [L. Zhang, Y. K. Takahashi, A. Perumal, and K. Hono, JMMM 322, 2658 (2010)]. This film had an average grain size of 6 nm, and HAMR statis test carried out at HGST Jan Jose Research Center demonstrated the recording density of 430 Gb/in$^2$, which was the highest HAMR recording density reported at that time [L. Zhang, Y. K. Takahashi, K. Hono, B. C. Stipe, J.-Y. Juang, and M. Grobis, JAP 109, 07B703 (2011)]. The Ag alloying is also considered to be beneficial to reduce the Curie temperature of the FePt phase for HAMR recording. Based on these investigations, we have also explored the possibility of growing (FePt)Ag-C granular thin films on FeTaC soft underlayers on glass substrates [A. Perumal, L. Zhang, Y. K. Takahashi and K. Hono, JAP 108, 083907 (2010)]. The choice of FeTaC SUL was based on our feasibility study of nanocrystalline soft magnetic underlayer [A. Perumal, Y. K. Takahashi and K. Hono, JAP 105, 07A304 (2009)]. Since FeTaC film is amorphous in the as-sputtered condition at room temperature, it is possible to grow (001) textured MgO interlayer by sputtering.
Then, (001) textured FePtAg-C granular films can be grown at an elevated temperature. During the annealing, the FeTaC amorphous film is crystallized to nanocrystalline soft-magnetic film. The resultant magnetization curve measured by Kerr magnetometer showed rather promising magnetic properties.

We have further modified the microstructure of the (FePt)Ag-C granular films and improved the squareness as shown in Fig. 1 (a). The film show strong perpendicular anisotropy with excellent squareness and the average grain size is 6 nm. The HAMR static test results (Fig. 1(b)) indicate that the recording density of 550 Gb/in$^2$ is achievable with this improved media [L. Zhang, Y.K. Takahashi and K. Hono, B.C. Stipe, J.-Y. Juang and M. Grobis, INTERMAG 2011, to be presented].

The investigations described above have been performed without considering specific requirements for the proposed HAMR technique, as the first priority was put into the realization of uniformly dispersed L1$_0$-FePt nanoparticles with perpendicular anisotropy. For applications as HAMR media for higher than 1 Tb/in$^2$, the following technical improvements are required.

1. Further optimization of the microstructure of L1$_0$-FePt granular films: D~4 nm, $\delta<10\%$, better saturation field distribution (SFD)
2. Better choice for spacer materials for the columnar growth of FePt magnetic grains
3. Metallic interlayer instead of MgO so that all layers can be processed with DC
4. Improvement of the thermal conductance to the substrate direction using a heat sink
5. Effect of soft exchange coupling for improved SFD
6. Processing the same microstructure of the magnetic layer using an alloy target

b. Proposed research approach

This research proposal is to improve the microstructure of FePt granular media further on glass disks so that the processed films can be tested with a HAMR spin stand tester. We will focus on the following technical issues and prepared samples will be supplied to ASTC sponsoring companies for HAMR recording tests. The followings are brief descriptions on our approach to solve above-mentioned individual technical issues:

1. Further optimization of the microstructure of L1₀-FePt granular film: D~4 nm, δ<10%, better saturation field distribution (SFD)

   Using C as a spacer material, we have demonstrated that well isolated 5-6 nm grains with a narrow size distribution can be processed. Our detailed TEM investigations suggested that there is no one-to-one correspondence between FePt grains and MgO underlayer grains. Therefore, the refinement of the MgO underlayer will not lead to further refinement of the FePt grains. To refine the magnetic grain size further, we need to increase the nucleation rate of the FePt particles. By modifying the process parameters as well as the spacer material and alloying elements (currently Ag), we will try to find a way to increase the nucleation rate of the FePt particles at the initial stage of the film growth. Through TEM observations, we will try to understand the underlying mechanism for the microstructure development, in particular gain size and their size distributions.

2. Better choice for spacer materials for columnar growth of the FePt magnetic particles

   We found C was the best spacer material to isolate FePt grains so far. However, C causes spheroidization of the FePt grains when the film thickness exceed 6 nm, hindering the columnar growth of the FePtAg particles with a sufficient aspect ratio. Currently, we achieved 6 nm thickness in 5 nm grain size. We aim to achieve the aspect ratio of columnar grains 2:1. We believe that the spheroidization is due to the high driving force for the phase separation between FePt and C. Considering thermodynamical parameters, we will select a spacer material that has less driving force for the phase separation. In our previous investigations, we tested SiO₂ as a spacer material and found that it tends to form interconnected microstructure of FePt grains [T. O. Seki, Y. K. Takahashi, and K. Hono, JAP 103, 023910 (2008)]. Thus, we will try...
mixtures of these possible spacer layers so that an appropriate phase separation tendency to achieve both particle isolation and columnar growth.

3. Metallic interlayer instead of MgO so that all layers can be processed with DC

We found MgO is the best underlayer material so far because RF sputtered MgO layers develop strong (001) texture on amorphous substrates, on which FePt particles show strong (001) texture. However, MgO tend to cause dusts during sputtering processes and the usage of RF sputtering degrade the efficiency of disk manufacturing. Thus, we will explore an alternative underlayer for the FePt (001) growth that can be grown by the DC sputtering process. Possible materials are the composites of metal and oxides.

4. Improvement thermal conductance toward the substrate direction using heat sink

In our previous investigations, we did not make any consideration on the thermal conductance. Films were grown on thermally oxidized Si, so the heat generated by laser spots are considered to transfer from the magnetic layer to the substrate through thick oxide layer. Therefore, we will try to introduce heat sink to the above (FePt)Ag-C granular martial. Since 550 Gb/in$^2$ has been achieved even with the current (FePt)Ag-C films with a thick $a$-SiO$_2$ layer, we expect improved HAMR performance with an improved thermal conductance.

5. Effect of exchange coupling for improved SFD

We are the first group that demonstrated the potential of exchange coupled FePt media experimentally [Y. K. Takahashi and K. Hono, APL 84, 383 (2004). and Y. K. Takahashi, K. Hono, S. Okamoto, and O. Kitakami, JAP 100, 074305 (2006)] . As we have shown previously, we will introduce plasma damage to the (FePt)Ag-C granular films to process A1/L1$_0$ FePt composite media. By this way, we will investigate the influence of exchange coupled media for the reduction of SFD while keeping the thermal stability. If we can reduce the coercivity while keeping the energy barrier higher than $80k_BT$, the temperature for writing can be substantially reduced and this will make designing HAMR heads much easier. The magnetization process will be examined by micromagnetic simulations in parallel to explain/predict the experimental result.

6. Processing the same microstructure of the magnetic layer using an alloy target

We employed co-sputtering to process the high quality (FePt)Ag-C granular films so far. Here, we will optimize the composition of alloy target so that the recording layer
can be processed in the existing industrial production lines using a single alloy target at a substrate temperature below 600°C.

Facilities
The Magnetic Materials Unit at NIMS has the following technical expertise to carry out this proposed research:
- thin film processing of multicomponent and multilayer films
- magnetic measurements using SQID and SQUID VSM
- microstructure characterization by high resolution TEM
- ferromagnetic resonance (FMR)
- theoretical and micromagnetic analysis of magnetic switching
- for other facilities, see http://www.nims.go.jp/apfim/

Likely outcome of research
Through this research, we aim to develop the HMAR media for the areal density higher than 1 Tb/in² by the end of the proposed research period. At the same time, we will try to understand the underlying mechanisms for the improvements of microstructures of the proposed media. The accumulated basic knowledge obtained through this work will provide an guiding principle to achieve a media structure for higher density HAMR. Since our approach is to investigate the way to process the media using the existing manufacturing facilities, it will be well complemented by the sponsoring media companies using their manufacturing lines.

Resources requested from ASTC and how they will be utilized

<table>
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<th>Item</th>
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</tbody>
</table>

Home Institution:
National Institute for Materials Science: a national laboratory dedicated to materials science research under the umbrella of the Ministry of Education, Sports,
Contact information and biographical sketch of researcher.

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**EDUCATION**
1988.6  Ph.D. Materials Science & Engineering, The Pennsylvania State University,
1984.3  M.S. Materials Science, Tohoku University
1982.3  B.S. Materials Science, Tohoku University

**PROFESSIONAL EXPERIENCE**
2006 - present: Director of Magnetic Materials Unit
2004 - present: NIMS Fellow
1995 - 1998: Senior Researcher, National Research Institute for Metals (now NIMS)
1990-1995: Research Associate, Institute for Materials Research, Tohoku University

**ADJUNCT APPOINTMENTS**
04.3 - present: Professor, Graduate School of Pure and Applied Sciences, University of Tsukuba
03.10 - 04.3: Professor, Institute for Materials Science, University of Tsukuba
99.7 - 03.10: Associate Professor, Institute for Materials Science, University of Tsukuba

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Research Role: Thin film processing, TEM characterization

**EDUCATION**
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2009.5  Ph.D. Institute of Metal Research, CAS, Physics and Chemistry of Materials

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EDUCATION
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2008.3  M.S. Tohoku University, Physics
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PROFESSIONAL EXPERIENCE
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