The effect of Pt interlayers on the magnetic and structural properties of perpendicularly oriented barium ferrite media

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Perpendicular barium ferrite (BaM) films with Pt interlayers were successfully fabricated. The magnetic and structural properties of BaM films were compared with BaM films without Pt interlayers. It was found that perpendicular *c*-axis orientation was greatly improved for films with Pt interlayers. Perpendicular remanent squareness is increased, and the *c*-axis dispersion angle $\Delta\theta_{50}$ is decreased with Pt interlayers in BaM films. Also the coercivity was found to increase for films with Pt interlayers. A relative increase in perpendicular nucleation sites over in-plane and/or random nucleation sites contributes to the improvement in perpendicular *c*-axis orientation. The increase in coercivity may be explained by a weakening of magnetostatic interactions among BaM grains, due to magnetostatic isolation by the nonmagnetic Pt interlayers and the interdiffusion between Pt layers and BaM layers during high temperature *ex situ* annealing. © *1999 American Institute of Physics.* [S0021-8979(99)68608-X]

I. INTRODUCTION

The *c*-axis perpendicularly oriented BaM thin films are promising candidates for use as a high-density perpendicular recording medium. In particular, they are one of the few perpendicular media which have a remanent squareness close to one, which is believed to be essential for thermal stability against demagnetization. Many kinds of underlayers, such as ZnO,[1] thermally oxidized silicon (SiO_2),[1,2] Pt,[3] and AlN,[4] have been used to promote perpendicular *c*-axis orientation in BaM films.

Compared with longitudinal recording media, perpendicular media may be made to be relatively thick. With the above underlayers, such as Pt and SiO_2, the perpendicular *c*-axis orientation becomes worse as the BaM film thickness increases, as shown later. To achieve better perpendicular *c*-axis orientation for thicker films, Pt interlayers were added into the barium ferrite films. This article thus describes in detail the effects of Pt interlayers on both the magnetic and the crystalline structural properties of BaM films. A mechanism which explains the effect of the Pt interlayers in enhancing the perpendicular anisotropy, is also described.

II. EXPERIMENT

BaM thin films and Pt films were deposited by radio-frequency (rf) diode sputtering in a Leybold *Z*-400 sputtering system. A base pressure of below 1×10^{-6} Torr was achieved before deposition. Pt was deposited in pure Ar gas, with a pressure of 5.0 mTorr and a deposition rate of about 100 Å/min. For all the films, a 500-Å-thick Pt underlayer was first deposited onto a thermally oxidized silicon (SiO_2/Si) substrate. The Pt interlayer thickness was varied. Stoichiometric $BaFe_{12}O_{19}$ thin films were deposited in a mixture of Ar and O_2 with a total pressure of 5.7 mTorr and a deposition rate about 25 Å/min. The flow rate ratio of Ar and O_2 mixture was 67/12 sccm. All the deposited BaM films were annealed in a furnace at a temperature of 800 °C for about 20 min, then gradually cooled in air.

The magnetic properties of the films were studied using either an alternating gradient magnetometer or a vibrating sample magnetometer (VSM). The torque curves were measured using a torque magnetometer at a field of 12 000 Oe. The perpendicular anisotropy field H_k was calculated from the peak-to-peak torque values. The crystalline structures of the films were characterized by a Cu $K\alpha$ x-ray diffractometer. A Philips EM420T transmission electron microscope (TEM) was used to characterize the grain size and grain orientation.

III. RESULTS

The dependence of remanent squareness and coercivity on BaM film thickness is shown in Fig. 1. In-plane loops were also measured to detect the in-plane oriented grains in perpendicular BaM films. Perpendicular remanent square-

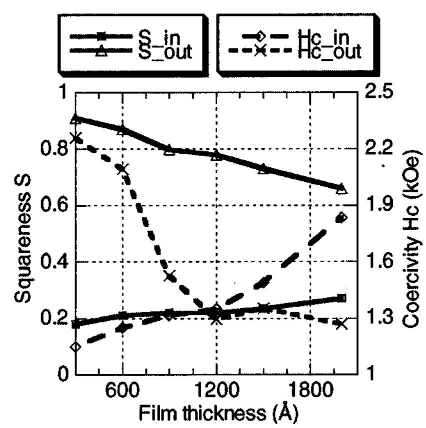

FIG. 1. Film thickness dependence of in-plane squareness *S_in*, perpendicular squareness *S_out*, in-plane coercivity H_c*_in*, and perpendicular coercivity H_c*_out* for single layer BaM thin films.

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TABLE I. Structure and magnetic properties of BaM samples A and B.

Film	Film structure	Squareness S perpendicular	in-plane	H_c (kOe)	M_s (emu/cc)	K_u erg/cc ($\times 10^6$)
A	BaM 900 Å/ Pt 500 Å/ SiO_2/Si	0.8	0.22	1.5	200	1.3
B	(BaM 300/Pt 150)$_3$/Pt 350 Å/SiO_2/Si	0.95	0.11	2.5	220	1.7

ness decreases gradually from about 0.9 to about 0.7 with an increase in film thickness from 300 to 2000 Å, while in-plane remanent squareness increases gradually from 0.18 to 0.27. Perpendicular coercivity was found to decrease with increasing film thickness from 2.3 to 1.3 kOe, and in-plane coercivity was found to increase from 1.2 to 1.8 kOe. Perpendicular magnetocrystalline anisotropy constant K_u and anisotropy field H_k were also calculated based on the torque measurements. As BaM film thickness increases from 300 to 600 Å or larger, K_u decreases from 1.7×10^6 to 1.3×10^6 erg/cc, with H_k decreasing from 18.2 to 12.9 kOe. The above results suggest a deterioration of perpendicular *c*-axis orientation and a decrease of perpendicular coercivity with an increase in BaM film thickness, which is undesirable for perpendicular recording media.

To improve the perpendicular orientation for BaM films, Pt interlayers were added between BaM films, and compared with BaM films without Pt interlayers. Two BaM samples A and B were fabricated. The total BaM film thickness is 900 Å for both samples A and B, while sample B has two 150-Å-thick interlayers. The structure of samples A and B and their magnetic properties are summarized in Table I. The in-plane and perpendicular *MH* loops for both samples A and B are shown in Fig. 2. With Pt interlayers, perpendicular remanent squareness increases from a value of 0.8 to 0.95, while in-plane remanent squareness decreases from a value of 0.22 to 0.11. The perpendicular magnetocrystalline anisotropy constant K_u also increases from 1.3×10^6 to 1.7×10^6 erg/cc. The above results indicate a better perpendicular *c*-axis orientation for sample B. The saturation magnetization (M_s) of both samples A and B is about the same, 200 and 220 emu/cc, respectively. In addition, sample B has a coercivity of 2500 Oe, while sample A has a coercivity of only 1500 Oe.

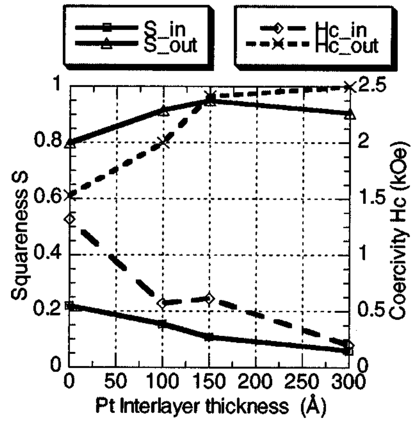

FIG. 3. Pt interlayer thickness dependence of S_in, S_out, H_c_in, H_c_out. The structures of all BaM films are the same as sample B except for the variation in Pt thickness as noted.

The effect of Pt interlayer thickness on magnetic properties of BaM films is shown in Fig. 3. The structure of all samples is the same as that of sample B. The Pt interlayer thickness ranges from 0 to 300 Å. The perpendicular squareness is above 0.9 for all films with interlayers. The coercivity is greater than 2 kOe for films with interlayers, compared with a coercivity of 1500 Oe for films without interlayers. Two Pt interlayers of 100 Å are enough to produce perpendicular remanent squareness above 0.9.

δM curves were also measured for samples A and B and are shown in Fig. 4. There are only negative peaks for barium ferrite films A and B, which indicates strong magnetostatic interactions among BaM grains in the perpendicular direction for both films. Compared with sample A, the negative δM peak is 1/3 smaller for sample B, which indicates weaker magnetostatic interactions for sample B.

Similar x-ray diffraction (XRD) results were obtained for samples A and B. Only (006), (008), and (0014) peaks, which indicate that the *c* axis is perpendicularly oriented, are observable. Rocking curves were also measured. The *c*-axis dispersion angle $\Delta\theta_{50}$ was measured as the full-width at half-maximum of the rocking curve at the XRD peak (008) for

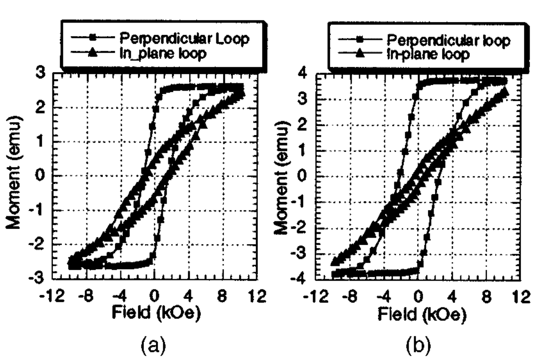

FIG. 2. In-plane and perpendicular *MH* loops for (a) sample A and (b) sample B.

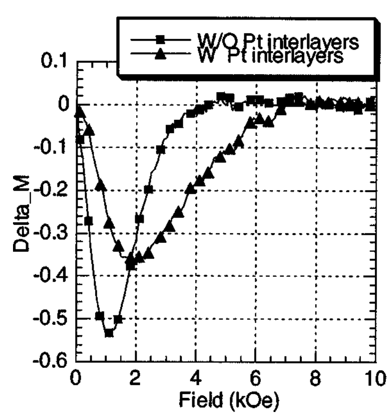

FIG. 4. δM curves for samples A and B measured by VSM.

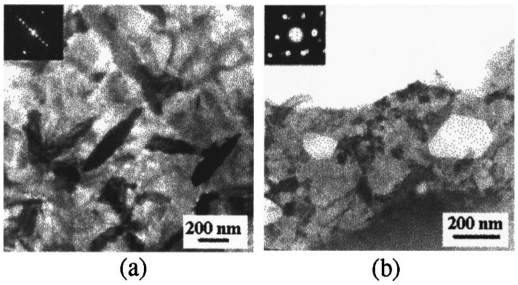

FIG. 5. TEM plan-view BF micrographs and microdiffraction patterns for (a) sample A and (b) sample B.

BaM films. It was found that $\Delta\theta_{50}$ for samples A and B is about 8° and 6°, respectively. Sample B has a better perpendicular *c*-axis texture, which agrees with the magnetic property measurements.

TEM plan-view bright field (BF) micrographs and microdiffraction patterns of samples A and B are shown in Fig. 5. For sample A, some acicular grains are clearly seen in addition to platelet-like grains, as shown in Fig. 5(a). However, for sample B, hexagonal platelet-like grains are observed with acicular grains rarely seen, as shown in Fig. 5(b). The acicular grains are either *c*-axis in-plane oriented or randomly oriented. The electron diffraction from one acicular grain shown on the left-top corner of Fig. 5(a) clearly shows *c*-axis in-plane orientation. The platelet-like grains are *c*-axis perpendicularly oriented, as confirmed by the electron diffraction pattern from one platelet-like grains on the left-top corner of Fig. 5(b). The above results clearly indicate that the Pt interlayers enhance the growth of the perpendicularly oriented platelet-like grains and suppress the growth of the in-plane and randomly oriented acicular grains.

IV. DISCUSSION AND CONCLUSION

Pt interlayers play an important role in improving the magnetic properties and crystallographic characteristics of BaM films. Without Pt interlayers, a gradual deterioration of the perpendicular *c*-axis orientation with an increase of BaM film thickness was observed; while with two Pt interlayers, a perpendicular remanent squareness of 0.95 can still be achieved for a 900-Å-thick BaM film. By adjusting the number of Pt interlayers, the higher perpendicular remanent squareness can be maintained with increasing BaM film thickness. From TEM measurements, it is clear that the enhancement in perpendicular *c*-axis orientation for films with Pt interlayers is related to the suppression of the growth of in-plane and/or randomly oriented acicular grains.

The mechanism for improving the perpendicular *c*-axis orientation with Pt interlayers is believed to be a relative increase in the nucleation sites for perpendicularly oriented grains over the nucleation sites for in-plane and/or randomly oriented grains. The as-deposited BaM film is still amorphous before *ex situ* annealing. It is believed that there are two kinds of nucleation sites for crystallization of BaM during *ex situ* annealing. One kind of nucleation site is at the interfaces formed between BaM layers and Pt layers. It was reported that the as-deposited BaM films are not completely disordered, but rather have an ordered local structure around Fe atoms, and the direction of order determines the crystallization direction during annealing.[5] So a local order of BaM atoms may be arranged at the Pt layer interface, which is favorable to crystallize perpendicularly oriented BaM films. Thus Pt and BaM interfaces are believed to form nucleation sites which favor perpendicularly oriented grains.[6] In addition, it is also believed that there are some randomly oriented nucleation sites in the bulk of BaM films. The total number of random nucleation sites increases as the film thickness increases. While perpendicular nucleation sites dominate random nucleation sites for very thin films, the effect of random nucleation sites will become larger with an increase in film thickness. So a deterioration of perpendicular orientation with an increase in film thickness is believed to be caused by the relative increase in random nucleation sites. Pt interlayers in BaM films have the effect of increasing the number of interfaces. By adding Pt interlayers, perpendicular nucleation sites at the interfaces increase. So perpendicularly oriented platelet-like grains are grown during *ex situ* annealing of films with Pt interlayers. Thus Pt interlayers effectively improve the perpendicular *c*-axis orientation.

With Pt interlayers, the coercivity was found to increase from 1500 to 2500 Oe. At the same time, a decrease in the δM values was observed. The smaller δM value suggests a weaker magnetostatic interaction among BaM grains. The drop of the δM value may be related to the magnetostatic isolation of BaM films by nonmagnetic Pt interlayers and the interdiffusion between Pt layers and BaM layers during annealing, all of which have the effect of decreasing magnetostatic interactions among BaM grains. So the decrease in magnetostatic interactions may cause the increase of coercivity for BaM films with Pt interlayers.[7]

In conclusion, BaM films with Pt interlayers were successfully fabricated and characterized. BaM films with Pt interlayers have a significantly improved perpendicular *c*-axis crystalline texture and a larger coercivity compared to films without Pt interlayers.

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