

Growth of Perpendicular Barium Hexaferrite Thin Film Media on a Pt Underlayer for High Density Perpendicular Magnetic Recording

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Abstract — Excellent c-axis perpendicularly oriented barium hexaferrite thin films have been achieved on both (111) and (100) Pt underlayers by either conventional rf diode or magnetron sputtering. TEM cross section study has revealed a sharp interface between the barium hexaferrite and the Pt underlayer, indicating no extensive interfacial reactions between layers. This has enabled fabrication of very thin barium hexaferrite films as thin as 50Å. A 50Å thick Pt underlayer is sufficient to produce a good c-axis perpendicular orientation in the barium hexaferrite layer. High coercivity (above 2000 Oe) perpendicular barium hexaferrite media can be obtained in a film thickness range suitable for high density perpendicular recording.

I. INTRODUCTION

Due to thermal instabilities, longitudinal recording is not expected to be able to achieve a 100 Gbit/in² recording density. Perpendicular magnetic recording is more favorable at such a high recording density due to reduced demagnetizing fields in the recorded transition and the ability to use thinner media. To achieve the perpendicular mode at high recording densities, a medium is required to have not only a large perpendicular anisotropy to support the perpendicular magnetization, but also a high mechanical hardness to allow closer head-disk separation and a good chemical stability to maintain adequate medium lifetime. Barium hexaferrite is one of the few candidates which meet the requirements.

Many research efforts have been made to deposit high quality hexaferrite films over the last decade[1]-[5]. The strong dependence on processing conditions makes it difficult to fabricate barium hexaferrite thin films with good perpendicular c-axis orientation. The current research methodology, which produces good c-axis perpendicular orientation, uses the target facing type sputtering (TFTS) technique[1]-[3]. A high temperature *in-situ* annealing during deposition is generally required to produce such films.

In this paper, we show that a Pt underlayer can enhance the c-axis perpendicular orientation of barium hexaferrite. With the Pt underlayer, barium hexaferrite films can be deposited at room temperature by either conventional rf diode or magnetron sputtering techniques which are widely used in industry. After deposition at room temperature, strong c-axis perpendicular orientation can be attained by rapid *ex-situ* annealing. In this way, very thin hexaferrite films can be made.

II. PROCESSING AND CHARACTERIZATION

The films involved in this work were fabricated as follows. Single crystal silicon with a 5000Å thick oxidized surface was used as a substrate. Both Pt and

barium hexaferrite (BaFe₁₂O₁₉) layers were deposited by conventional rf diode sputtering in a Leybold Z-400 sputtering system with a base vacuum < 6 x 10⁻⁷ Torr. The sputtering conditions for the Pt layer were fixed at a power density of 1.1 watts/cm² and a total Ar gas pressure of 5 mTorr. Reactive sputtering was used to deposit the barium hexaferrite overlayer. The partial pressure ratio between Ar and O₂ was kept at 4.4/0.6. The power and the total gas pressure were chosen to be the same as that used for Pt deposition. In the as-deposited state, the Pt layer is polycrystalline, while the barium hexaferrite is amorphous. Crystallization of the barium hexaferrite layer took place during the post deposition annealing step at 800°C for about 15 min in air. The microstructure of the film and the interface between layers were studied by transmission electron microscopy (TEM). X-ray diffraction was used to characterize the crystal phase and orientation. All the magnetic properties measurements were performed on a DMS-1660 Torque/VSM dual magnetometer.

III. RESULTS AND DISCUSSION

A 2500Å thick Pt underlayer with predominant (111) texture was first deposited on a thermally oxidized silicon substrate. A 600Å thick barium hexaferrite layer was subsequently deposited on top of it. After annealing, a very strong c-axis perpendicular orientation developed in the barium hexaferrite layer as indicated by the predominant (00l) peaks in the X-ray diffraction spectrum shown in Fig. 1.

We previously reported that barium hexaferrite thin films with c-axes nearly in-plane oriented can be deposited on thermally oxidized silicon substrates by using exactly the same sputtering conditions[6]. For comparison, the x-ray diffraction spectrum for an in-plane barium hexaferrite thin film is also shown in Fig. 1. Without the Pt underlayer, the c-axes of the barium hexaferrite crystallites are mostly lying in the film plane as indicated by the strong (110) and (220) peaks.

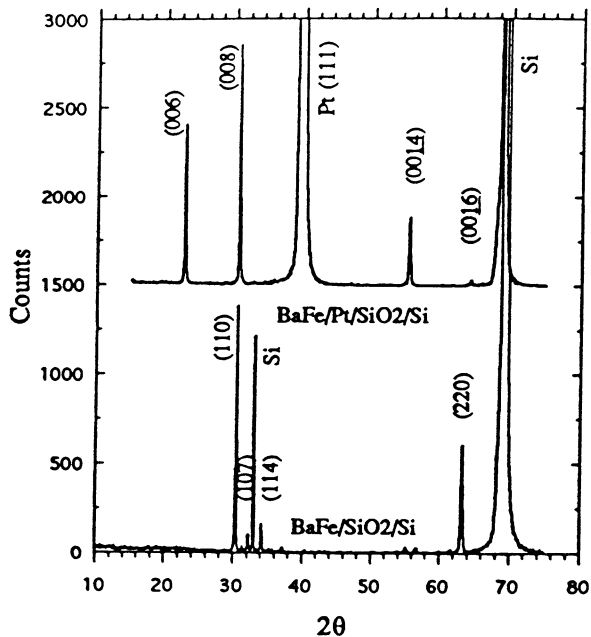


Fig. 1: X-ray diffraction spectra for films with and without Pt underlayer.

Since X-ray diffraction measurements may not provide enough resolution to detect a small amount of c-axis in-plane oriented grains in a perpendicular film[5], both hard and easy axis hysteresis loops of the perpendicular film were measured. The results are shown in Fig. 2. The nearly closed hard axis loop indicates the prevailing c-axis perpendicular orientation of the film. The saturation magnetization of this film is about 380 emu/cc, which is very close to the value of bulk barium hexaferrite single crystals. The coercivity of the easy axis loop is about 1.2 KOe. The magnetocrystalline anisotropy constant K_u , determined from a torque magnetometer measurement is about 3.15×10^6 erg/cc, a value close to that of bulk barium hexaferrite. This is also an indication of the strong c-axis perpendicular alignment. TEM microstructural studies of a planar view sample showed that grains have a rather equiaxed shape, instead of an acicular shape which was previously observed for barium hexaferrite crystal grains with in-plane c-axis orientation[5]. The average grain size is found to be on the order of 2000Å.

Since the basal plane of the hcp crystal structure has the same close-packed atomic arrangement as the (111) plane of the fcc structure, it is tempting to attribute the strong perpendicular orientation of the barium hexaferrite to an epitaxial relationship with the (111) Pt underlayer. However, our experiments with (100) Pt underlayers indicate this is not the case. Because of the close lattice match, a (100) oriented MgO single crystal was chosen to be a substrate for (100) Pt. First, 10Å of Fe was coated onto the (100) MgO substrate and then 150Å of Pt. These depositions were carried out at a substrate temperature of

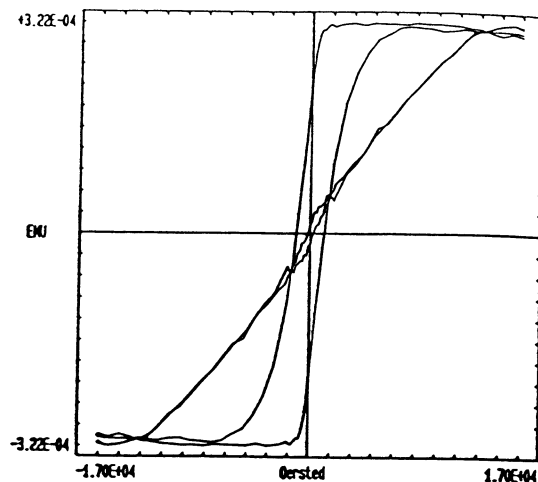


Fig. 2: Both easy and hard axis hysteresis loops of a perpendicular hexaferrite film with a Pt underlayer. 400°C. After the sample cooled down to room temperature, a 600Å thick barium hexaferrite layer was deposited. An X-ray diffraction spectrum of a crystallized film is shown in Fig. 3. The (111) Pt peak is almost absent. Instead, a strong (200) peak emerged due to the epitaxial growth on the (100) MgO crystal plane. However, the c-axes of the barium hexaferrite layer are still very well aligned in the perpendicular direction. This suggests that epitaxial growth is not directly responsible for the development of the strong perpendicular orientation in the barium hexaferrite layer.

A TEM cross section of a film with 300Å of Pt and 600Å of barium hexaferrite is shown in Fig. 4. The lattice fringes of the (0002) barium hexaferrite crystal basal plane are parallel to the film plane indicating a strong c-axis perpendicular orientation. It is noticed that the (0002) basal planes extend all the way up to the interface, indicating the absence of significant interfacial reactions. Since the ion milling rate for barium hexaferrite is faster than that for Pt during TEM sample preparation, the Pt region remains thick and shows no detailed contrast. During the cross sectional TEM study, we also observed that, in regions where the interface is not parallel to the overall film plane, which is essentially parallel to the (111) Pt crystal plane, barium hexaferrite lattice fringes tend to lie parallel to the local interface rather than to the (111) Pt crystal plane. This is consistent with our finding with (100) Pt underlayers that no epitaxy between (111) Pt and (0001) barium hexaferrite is required for the development of the perpendicular c-axis orientation. Presently, we have no clear understanding of how the Pt underlayer promotes the perpendicular c-axis orientation. This is to be resolved in future studies. We speculate that a primary role of the Pt is to change the interfacial

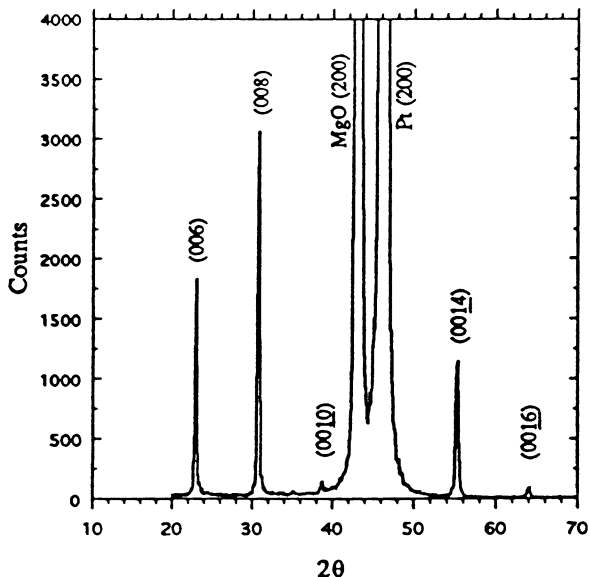


Fig. 3: X-ray diffraction spectrum of a film with BaFe/Pt on a (100) single crystal MgO substrate.

chemistry so as to promote the development of the self-texturing of (0001) barium hexaferrite by surface energy minimization.

For device applications, a thin Pt underlayer is desired to reduce the manufacturing cost. The effect of the underlayer thickness was therefore studied by varying the Pt layer thickness from 20Å to 1200Å while maintaining the barium hexaferrite layer thickness at 600Å. Within this range, all films are found to have predominant c-axis perpendicular orientation from their x-ray diffraction spectra. However, at a Pt layer thickness below 50Å, a slightly opened hard axis hysteresis loop was observed indicating that the c-axes are not perfectly aligned in the perpendicular direction. This is attributed to the existence of discontinuities or island-like surface topology in the thin Pt layer. Since a c-axis in-plane orientation tends to occur without the Pt underlayer, in-plane barium hexaferrite crystallites form in regions of discontinuities which contribute to the in-plane hysteresis. Therefore, a smooth and continuous Pt layer is required to produce good perpendicular barium hexaferrite films when a thin Pt underlayer is used.

The easy axis coercivity dependence on the Pt layer thickness is shown in Fig. 5. Notice that it peaks at around 100Å; and the curve resembles the classical grain size effect on coercivity[7]. When the Pt is thin, barium hexaferrite crystal grains with c-axis perpendicular orientation nucleate on top of Pt grains while c-axis in-plane oriented grains occur in regions of discontinuities which surround the island-like Pt grains. Therefore, high

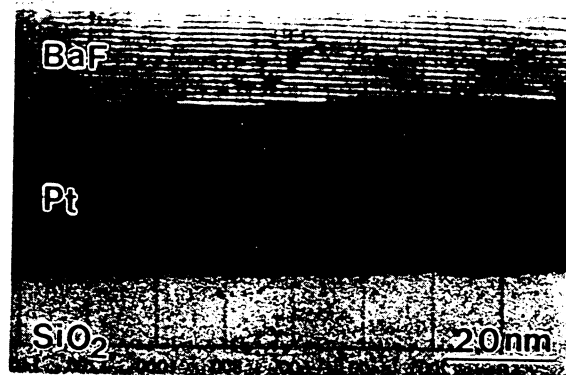


Fig. 4: TEM cross section of a BaFe/Pt multilayer.

angle grain boundaries form which prevent the formation of large crystallites in the barium hexaferrite layer. Larger grain size occurs with a thick underlayer because of the elimination of discontinuities in the Pt layer.

Similar phenomena were also observed when the effect of barium hexaferrite thickness was studied as shown in Fig. 6. A peak coercivity of 3200 Oe was obtained with a 200Å thick barium hexaferrite film and a 580Å Pt underlayer. This peak is probably caused by voids isolating grains in the thin barium hexaferrite layer. For current perpendicular magnetic recording, the medium thickness of interest is in the neighborhood of about 1000Å. Within this range, the coercivity is above 2000 Oe as shown in Fig. 6. The x-ray diffraction spectra for

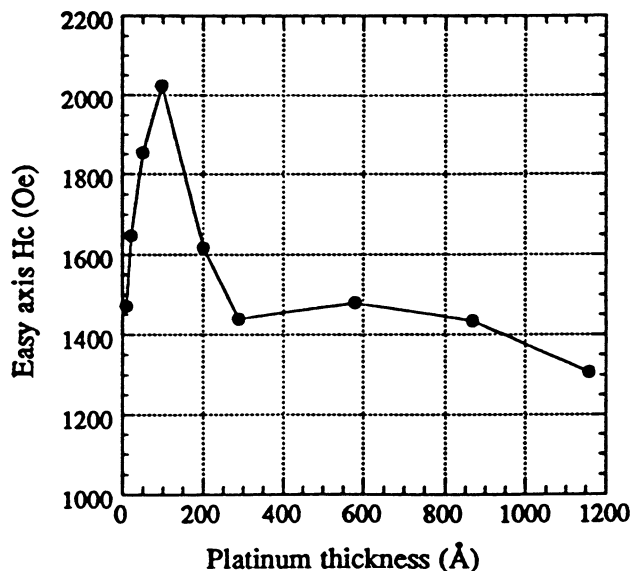


Fig. 5: Easy axis coercivity dependence on Pt layer thickness.

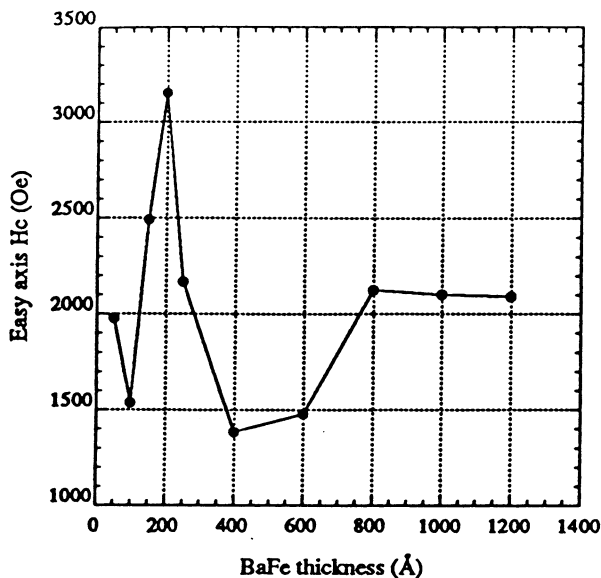


Fig. 6: Easy axis coercivity dependence on BaFe layer thickness.

several different barium hexaferrite layer thicknesses are shown in Fig. 7. Notice that even a 50Å (equivalent to about two unit cells) thick barium hexaferrite film shows a strong c-axis perpendicular texture.

IV. CONCLUSIONS

A Pt underlayer has been demonstrated to enhance the c-axis perpendicular orientation of barium hexaferrite thin films. Measurements from x-ray diffraction, hard axis hysteresis loops, torque magnetometry and TEM microstructural studies all confirm an excellent c-axis perpendicular orientation of the films. With the Pt underlayer, conventional rf diode or magnetron sputtering can be used to fabricate the perpendicular films. TEM cross sections show a sharp interface between the barium hexaferrite layer and the Pt underlayer, indicating no extensive interfacial reactions between the layers. Very thin (50Å) barium hexaferrite films can be made. The perpendicular c-axis orientation of the barium hexaferrite does not depend upon epitaxy with the Pt underlayer, but may instead be determined by surface energy considerations. In the region of interest for current perpendicular recording technology, the coercivity of the media exceeds 2000 Oe which is favorable for high density recording.

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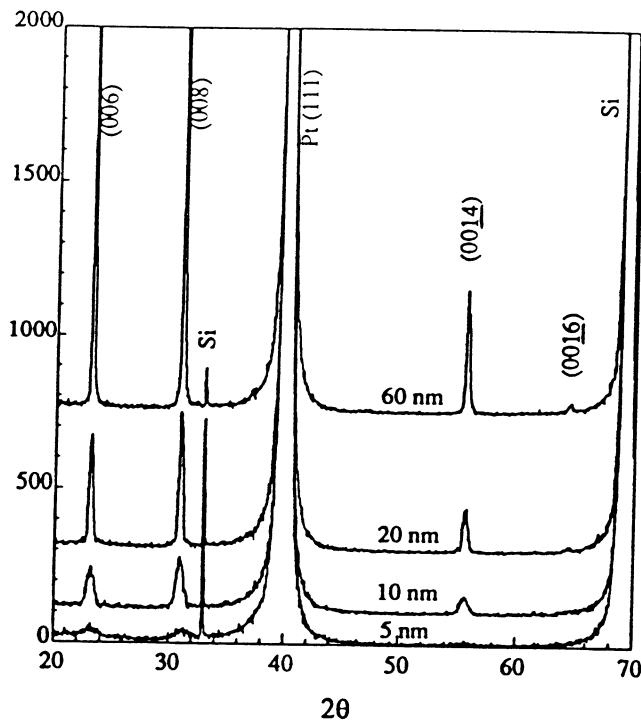


Fig. 7: X-ray diffraction spectra for films with different BaFe layer thicknesses.

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