Barium and Strontium Ferrite Perpendicular Thin Film Media with a Sendust Soft Magnetic Underlayer

Zailong Zhuang, *Member, IEEE*, Bo Bian, Robert M. White, *Fellow, IEEE*, and David E. Laughlin

***Abstract*—The possibility of using sendust (FeAlSi) as the soft magnetic underlayer for hexagonal barium ferrite (BaM) and strontium ferrite (SrM) was studied. Sendust films were found to retain their soft magnetic properties with a rapid thermal anneal (RTA) at 800 C for 60 s, which is necessary to crystallize the as-deposited amorphous BaM and SrM films. Several film structures with sendust films as the soft underlayer were studied and compared. Strong hcp (00l) texture and bcc (110) texture were obtained on the BaM(SrM)/Pt/buffer/FeAlSi/Si multi-layer structure films, as indicated by the strong hcp (006), (008) and (0014) reflections for BaM(SrM) layer and bcc (110) reflection for the sendust underlayer from X-ray diffraction measurements.**

***Index Terms*—Barium ferrite, multi-layer, sendust, soft underlayer, strontium ferrite, textured growth.**

I. Introduction

M-TYPE barium ferrite (BaM) and strontium ferrite (SrM) thin films which have hexagonal crystal structure are attractive candidates for overcoat free magnetic recording due to their large uniaxial anisotropy, high chemical stability, and corrosion resistance [1]–[4]. To use them as high-density perpendicular recording media, a suitable soft magnetic underlayer needs to be developed. A soft magnetic underlayer increases the perpendicular component of the recording field without broadening the head field for both inductive thin film heads and single pole type recording heads. The perpendicular component of the head field varies less rapidly with y in the presence of the soft magnetic underlayer [5]. While there are many research reports on the developments of soft underlayers for CoCr based perpendicular media, there is still no research report on making suitable soft underlayers for BaM and SrM media. The special requirement for use as the soft underalyer for BaM and SrM is to maintain the soft magnetic properties during either *in-situ* or *ex-situ* high temperature annealing process, which limits the possible choices of soft magnetic materials. Sendust was reported to have good soft magnetic properties with high temperature annealing around 400 °C–600 °C [6], thus may be a reasonable choice. In addition, the c-axis orientation needs to be controlled to be perpendicular to the film plane for perpendicular recording application. There have been many reports on controlling c-axis orientation of BaM and SrM films perpendicularly [2]–[4]. In this study, we focus on studying the magnetic properties of sendust films, developing different film structure using sendust films as the underlayer, and controlling the perpendicular textured growth for BaM and SrM films.

Manuscript received February 14, 2000.

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Publisher Item Identifier S 0018-9464(01)07208-9.

II. Experimental

All the films were prepared by rf diode sputtering in a Leybold Z400 sputtering system. BaM and SrM films were sputtered in a mixture of argon and oxygen gas. The total pressure was fixed at 5.7 mTorr with the oxygen to argon ratio of 0.7/5. Sendust films were either deposited in pure argon gas or deposited in a mixture of argon and nitrogen gas. The total pressure was fixed at 10 mTorr with 0.5% nitrogen gas. Pt and SiO_2 were prepared with argon gas with a pressure of 5 mTorr. The target power was fixed at 100 W for all the films. Silicon substrates were used for all the films. The as-deposited films are amorphous, and the annealing was carried out for about 60 s at 800 °C using a RTA furnace oven.

The magnetic properties of the films were studied using either an alternating gradient magnetometer (AGM) or a vibrating sample magnetometer (VSM). The crystal structures and textures of the films were characterized by X-ray diffraction (XRD) using CuK_α radiation. A Philips EM420T transmission electron microscope (TEM) was used to characterize the film interface inter-diffusion and grain growth.

III. Results and Discussion

A. Magnetic and Structural Properties of Sendust Films

Sendust films in the as-deposited state show soft magnetic properties, with coercivity around 20 Oe. The saturation magnetization of the film is about 1000 emu/cc, while the remanent squareness is about 0.75. The as-deposited films are isotropic with no preferred easy-axis orientation. The crystalline structure for as-deposited sendust films is bcc (110). The effect of nitrogen reactive sputtering on the soft magnetic properties of sendust film was then investigated. With nitrogen gas reactive sputtering, sendust films show very soft magnetic properties in as-deposited state. The coercivity drops to 2 Oe and the saturation magnetization drops to 850 emu/cc for the as-deposited sendust films. The as-deposited films with nitrogen reactive sputtering are also isotropic with no preferred easy-axis orientation. The in-plane MH loops for as-deposited sendust films prepared in pure argon gas and as-deposited sendust films with nitrogen reactive sputtering are shown in Fig. 1(a) and (b) respectively. The effect of post-deposition RTA annealing on the soft magnetic properties of sendust films prepared in pure argon gas was also investigated. For all the films, the RTA post annealing was done in a nitrogen

(a)

(b)

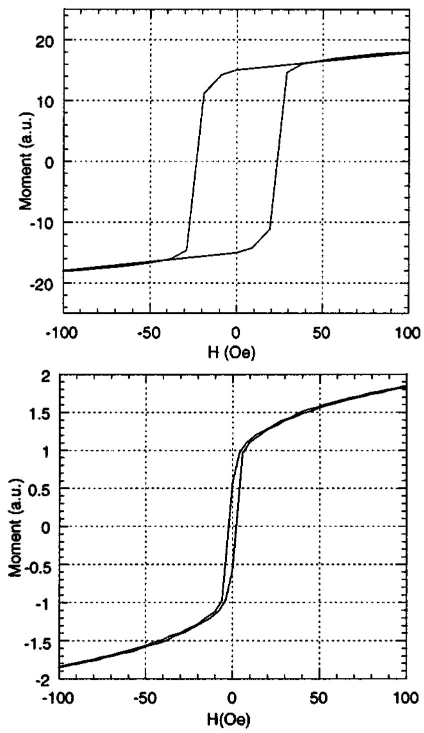

Fig. 1. In-plane MH loops for as-deposited sendust films on Si substrate (a) prepared in pure Ar gas (b) prepared with 0.5% N_2 gas.

atmosphere with a varied time from 0 to 20 minute at 600 °C. The coercivity of annealed sendust films was found to decrease from 20 Oe to 10 Oe with the annealing time with no change in saturation magnetization. The enhanced soft properties in annealed sendust films have been attributed to the presence of the ordered DO3 phase with the post annealing [6]. The soft magnetic properties and good annealing properties with sendust films make it a possible choice to be the soft underlayer for BaM and SrM films. It was found that BaM and SrM films show similar magnetic properties with sendust as the underlayer, and their properties would be reported together next.

B. Properties of BaM(SrM)/FeAlSi BI-Layer Films

The magnetic and structural properties of BaM(SrM)/FeAlSi bi-layer films on the silicon substrate were studied first. A 300 Å-thick sendust film was deposited on silicon substrate, and then a 900 Å-thick BaM(SrM) thin film was deposited directly on the sendust film. A post-deposited RTA annealing was applied for 60 s at 800 °C to crystallize BaM(SrM) layer. The top BaM(SrM) thin film layer was found to have a perpendicular coercivity around 3000 Oe and saturation magnetization about 280 emu/cc. The sendust film layer still keeps its soft magnetic properties with the high temperature annealing. The Hc and Ms of sendust films are about 50 Oe and 1000 emu/cc respectively.

The XRD curve for the bi-layer film is shown in Fig. 2. Weak (00l) reflection peaks were observed. Meanwhile, relatively stronger (107) and (114) reflection peaks were also observed for BaM(SrM) films with the bi-layer structure. Thus the BaM(SrM) layer has a weak c-axis texture. The dominant reflection is bcc (110) peak for the sendust film. The intensity

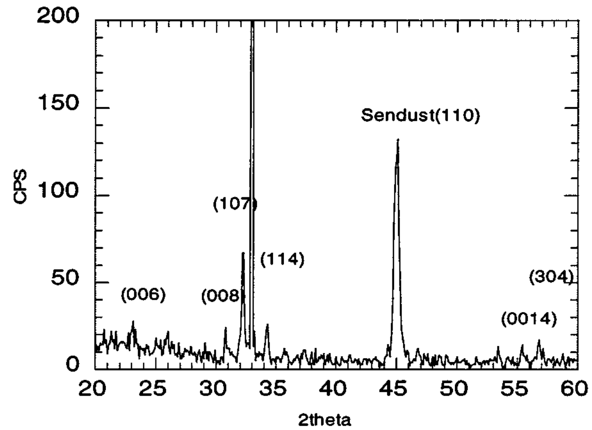

Fig. 2. The XRD curve for RTA annealed BaM(SrM)/FeAlSi bi-layer films.

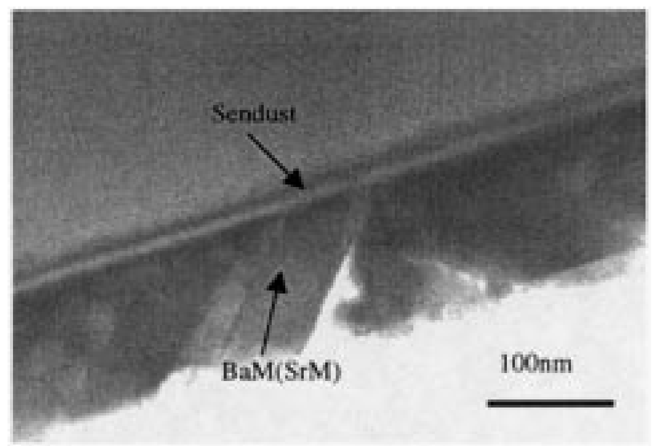

Fig. 3. The TEM cross section image for RTA annealed BaM(SrM)/FeAlSi bi-layer films.

of bcc (110) peak is about 20% weaker compared to that of the as-deposited sendust films.

The cross section TEM picture of the bi-layer film was taken and shown in Fig. 3. BaM(SrM) grains are clearly seen to be growing about 45 degree out of normal to the plane, which also indicates a weak c-axis texture for BaM(SrM) layer. The TEM indicates inter-diffusion between the crystallized BaM(SrM) layer and the sendust layer, as shown by the unclear interface. The inter-diffusion at BaM(SrM) and sendust interface is the reason for the increase in coercivity and a decrease of XRD (110) peak intensity for sendust films. The inter-diffusion is not very serious as indicated by the strong bcc (110) reflection peaks indicated by the XRD shown in Fig. 2. The above results show that sendust films still keep their soft magnetic properties with a little degradation of magnetic softness due to little inter-diffusion with BaM(SrM) at the interface through RTA annealing at 800 °C for a duration of 60 s.

C. Properties of BaM(SrM)/Pt/Buffer/FeAlSi Multi-Layer Films

With sendust films as the underlayer, BaM(SrM)/FeAlSi bi-layer films show very weak c-axis texture. Different processing parameters such as substrate bias voltage, pressure and target power have been studied with above bi-layer films,

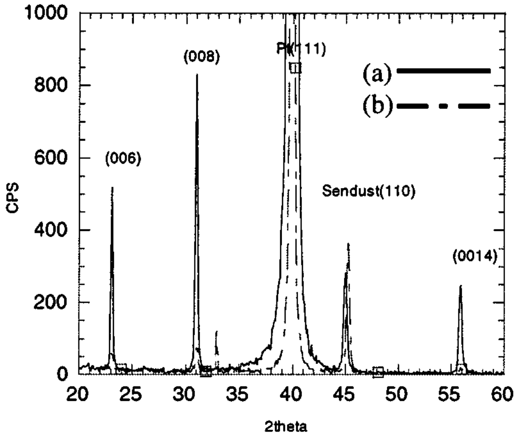

Fig. 4. XRD curves for BaM(SrM)/Pt/buffer/FeAlSi multilayer films: (a) amorphous BaM(SrM) as the buffer layer; (b) SiO_2 as the buffer layer.

and no clear dependence relationships were found. To improve the perpendicular c-axis texture for BaM(SrM), a Pt intermediate seedlayer was added under the BaM(SrM) layer [2]. Experimental results showed that there was a very serious inter-diffusion between Pt and sendust films during RTA annealing. Two kinds of buffer materials, sputtered SiO_2 and amorphous BaM(SrM), were found to be very effective in preventing the inter-diffusion. Thus, BaM(SrM)/Pt/buffer/FeAlSi multi-layer films with SiO_2 and amorphous BaM(SrM) as buffer layers were studied respectively. The thickness of the buffer layer and the Pt layer were kept at 50 Å and 200 Å respectively.

The XRD curves for BaM(SrM)/Pt/SiO_2/FeAlSi, and BaM(SrM)/Pt/BaM(SrM)/FeAlSi multi-layer films are shown in Fig. 4. The thickness of the sendust layer is 300 Å, while the thickness of BaM(SrM) layer is 600 Å. Strong bcc (110) reflection peaks are observed for all the multi-layer films with similar intensity for the sendust layer. However, there is big difference in the c-axis texture of BaM(SrM) films. The films with amorphous BaM(SrM) as the buffer layer show a very strong (00l) c-axis texture, while the films with SiO_2 as the buffer layer show a modest (00l) c-axis texture.

The in-plane and out of plane MH loops for BaM(SrM)/Pt/BaM(SrM)/FeAlSi multi-layer films are shown in Fig. 5(a) and (b) respectively. The MH loops are a combination of the MH loop of both the hard BaM(SrM) thin film and the soft sendust thin film. Through extraction, the top BaM(SrM) thin film layer was found to have a perpendicular coercivity around 2500 Oe and saturation magnetization about 280 emu/cc.

The cross section TEM image of the multi-layer film with 50 Å-thick amorphous BaM(SrM) as the buffer layer is shown in Fig. 6. The TEM picture indicates a clear interface between Pt and BaM(SrM), Pt and amorphous BaM(SrM), amorphous BaM(SrM) and sendust film. The lattice fringes of the (00l) BaM(SrM) crystal basal plane are parallel to the film plane indicating a strong c-axis perpendicular orientation. (00l) basal planes extend all the way up to the interface, indicating the absence of significant interfacial reactions. The 50 Å-thick BaM(SrM) buffer remains in the amorphous state, and the cross

(a)
(b)

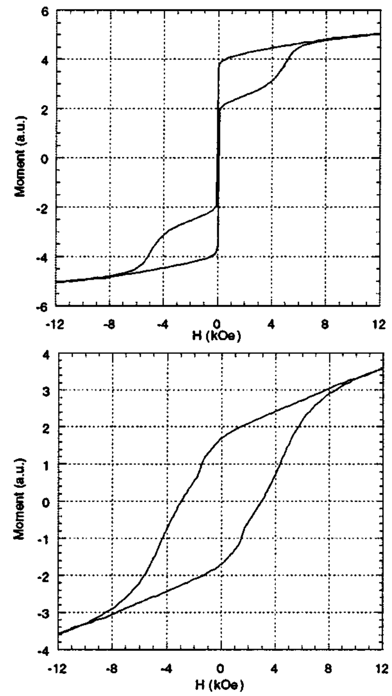

Fig. 5. In-plane (a) and perpendicular (b) MH loops BaM(SrM)/Pt/BaM(SrM)/FeAlSi multi-layer films.

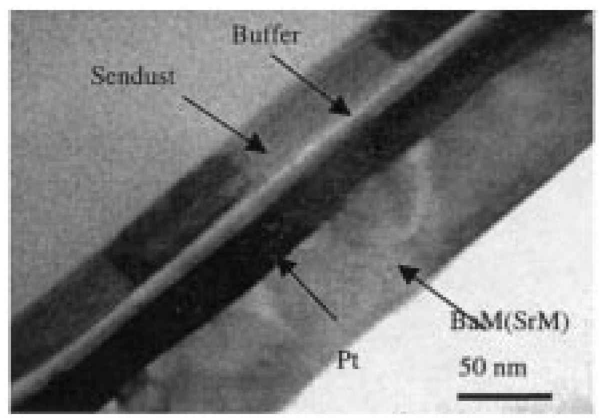

Fig. 6. The TEM cross section image for RTA annealed BaM(SrM)/Pt/BaM(SrM)/FeAlSi multilayer films.

section of the sendust film shows a well-defined columnar structure.

Above results show that the use of a Pt intermediate layer and the use of an amorphous BaM(SrM) buffer layer are very effective in improving the perpendicular c-axis texture for BaM(SrM), while keeping the soft magnetic properties of sendust film unchanged.

IV. Conclusion

Sendust was found to be very good choice for use as the soft magnetic underlayer for BaM and SrM perpendicular media. (00l) textured growth for BaM and SrM films can be achieved with a BaM(SrM)/Pt/buffer/FeAlSi multi-layer structure, while sendust films can retain their soft magnetic properties through post-deposition RTA annealing.

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