Journal of Magnetics 18(2), 155-158 (2013)

ISSN (Print) 1226-1750
ISSN (Online) 2233-6656
http://dx.doi.org/10.4283/JMAG.2013.18.2.155

FeCoB Films with Large Saturation Magnetization and High Magnetic Anisotropy Field to Attain High Ferromagnetic Resonance Frequency

Shigeki Nakagawa* and Ken-ichiro Hirata

Department of Physical Electronics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8552, Japan

(Received 31 May 2012, Received in final form 11 September 2012, Accepted 11 September 2012)

FeCoB films were being prepared on a Ru underlayer by using the oblique incidence of sputtered and back-scattered particles which have a high in-plane magnetic anisotropy field H_k above 400 Oe. It is suitable to attain such deposition condition when facing targets sputtering system. The in-plane X-ray diffraction analysis clarified that there is anisotropic residual stress which is the origin of the high in-plane magnetic anisotropy. The directional crystalline alignment and inclination of crystallite growth were also observed. Such anisotropic crystalline structures may affect the anisotropic residual stress in the films. The B content of 5.6 at.% was appropriate to induce such anisotropic residual stress and H_k of 410 Oe in this experiment. The film with B content of 6 at.% possessed large saturation magnetization of 22 kG and high H_k of 500 Oe. The film exhibited high ferromagnetic resonance frequency of 9.2 GHz.

Keywords : FeCoB, high magnetic anisotropy field, anisotropic residual stress, ferromagnetic resonance frequency

1. Introduction

FeCoB films prepared on the Ru underlayer by facing targets sputtering (FTS) technique revealed high in-plane magnetic anisotropy field H_k of 500 Oe as well as large saturation magnetization $4\pi M_s$ of 22 kG [1]. The origin of such a high H_k is attributed to the distortion of crystallite lattice and directional alignment of FeCo crystallites in the film. We have reported that oblique incidences of depositing particles to the growing surface in the FTS configuration and directional alignment crystallites are caused by the underlayer texture which leads to the distortion of crystallite lattice and directional alignments of FeCo crystallites [2]. However, the role of B in the FeCoB layer has not yet been fully clarified. B is well-known as an element that causes fine granulation due to its position in the Fe lattice interstitially, thus, improving soft magnetic properties. In this study, the effect of additional B to 200 nm-thick FeCoB layers on Ru underlayer was investigated. On the other hand, a soft magnetic film with high ferromagnetic resonance frequency f_r is required for high-frequency magnetic devices. Since the f_r is proportional to the square root of the product of $4\pi M_s$ and H_k. The FeCoB films mentioned above are suitable films for high frequency applications because of the large $4\pi M_s$ and high H_k. In this study, ferromagnetic resonance characteristics of the Ru/FeCoB layers were examined in high frequency regions of up to 15 GHz. The mechanism of the in-plane anisotropic residual stress is also being discussed.

2. Experimental

Ru(5 nm)/$(Fe_{70}Co_{30})_{100-x}B_x$(200 nm) films were fabricated on glass substrates at room temperature by DC facing targets sputtering (FTS) system. Easy axis of magnetic anisotropy in a plane of Ru/FeCoB film appears along the parallel direction to the facing direction of the targets in the FTS system [1-3]. In this paper, we define easy and hard axis directions as being parallel to the target and the orthogonal directions, respectively. B content in $(Fe_{70}Co_{30})_{100-x}B_x$ films can be changed from 0 to 23 at.% by using composite targets composed of $Fe_{70}Co_{30}$ alloy plates and B chips. Content of B in the films was determined by inductively coupled plasma (ICP) measurement. Argon gas pressures for Ru and $(Fe_{70}Co_{30})_{100-x}B_x$ layers were 6 mTorr and 1 mTorr, respectively. Magnetic properties were

*Corresponding author: Tel: +81-3-5734-3564
Fax: +81-3-5734-2513, e-mail: nakagawa@pe.titech.ac.jp

This paper was presented at the ICM2012, Busan, Korea, July 8-13, 2012.

evaluated by using a vibrating sample magnetometer (VSM) and crystal structures were investigated by out-of-plane and in-plane X-ray diffractometry (XRD). High frequency permeability was measured using KEYCOM MPM-01.

3. Result and Discussion

Figure 1(a), (b), (c) and (d) show *M-H* characteristics along easy and hard axes of the Ru/$(Fe_{70}Co_{30})_{100-x}B_x$ films with various content of B. Ru/FeCo film without B addition shows relatively high coercivities along easy and hard axes as shown in Fig. 1(a). The high coercivities may be caused by a rotatable anisotropy based on the perpendicular magnetic anisotropy caused by the residual stresses. The films with B content between 4 to 13 at.% show low coercivities as well as hard axis directions. The high magnetic anisotropy field can be observed in the films with B content between 4 to 13 at.% as shown in Fig. 1(b) and (c). High in-plane magnetic anisotropy field H_k of 410 Oe was observed at the B content of 5.6 at.%. Figure 2 indicates the change of H_k as a function of B content in the $(Fe_{70}Co_{30})_{100-x}B_x$ layers. Increase of B content up to 5.6 at.% causes the improvement of H_k of the Ru/FeCoB film. Excess content of B above 8 at.% causes degradation of H_k.

Figure 3 shows out-of-plane XRD diagrams of Ru/ $(Fe_{70}Co_{30})_{100-x}B_x$ layers for various B contents. Increase of (110) diffraction intensity of bcc-FeCo was observed while B content is increased up to 10 at.%. Addition of B, up to 10 at.%, is effective to improve FeCo crystallization and (110) orientation in the film. The film with B content above 13 at.% indicated disappearance of FeCo (110) diffraction and thus, turned into an amorphous structure. It should be noted that the (110) peak position, indicated

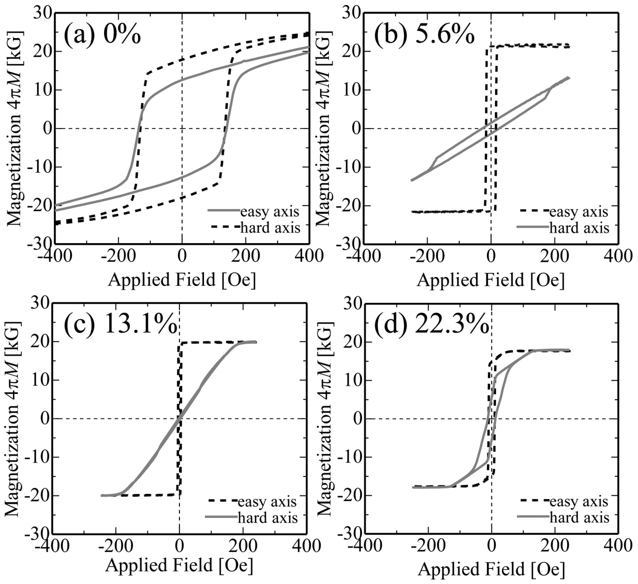

Fig. 1. M-H curves along easy and hard axes of Ru/$(Fe_{70}Co_{30})_{100-x}B_x$ layers for various B content of (a) 0%, (b) 5.6%, (c) 13.1% and (d) 22.3%.

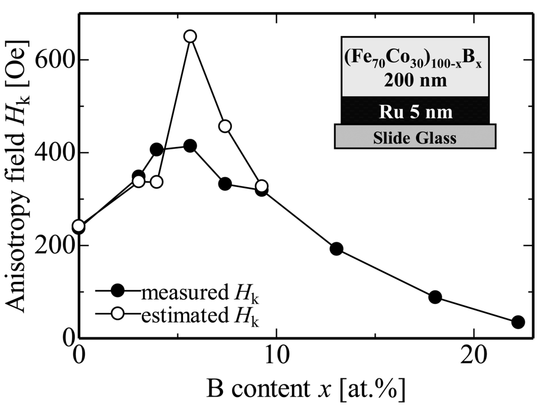

Fig. 2. Changes of H_k as a function of B content in the $(Fe_{70}Co_{30})_{100-x}B_x$ layers. Solid and open circles correspond to the measured and the estimated values.

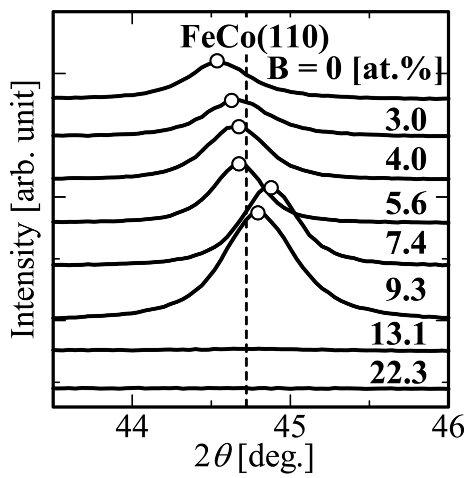

Fig. 3. Out-of-plane XRD diagrams of Ru/$(Fe_{70}Co_{30})_{100-x}B_x$ layers for various B contents.

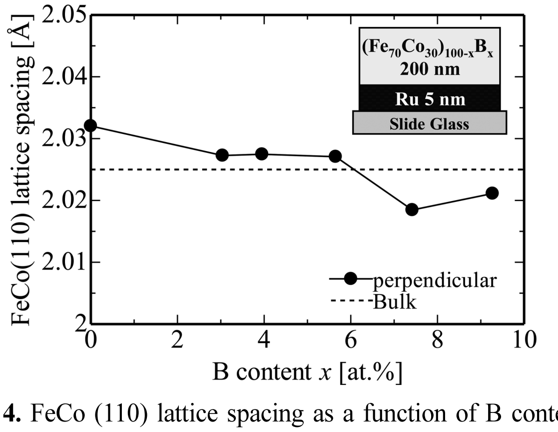

Fig. 4. FeCo (110) lattice spacing as a function of B content.

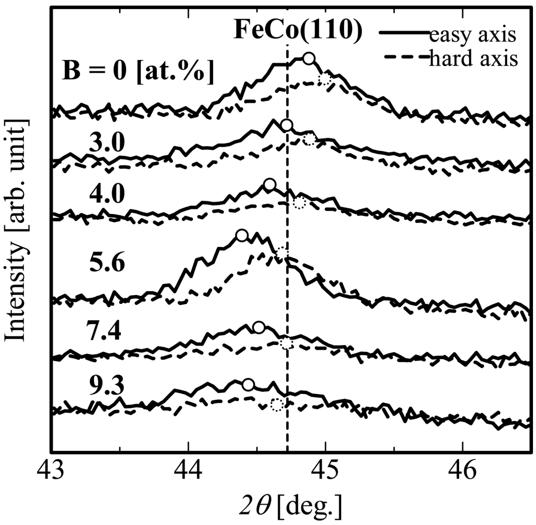

Fig. 5. In-plane XRD diagrams of Ru/$(Fe_{70}Co_{30})_{100-x}B_x$ layers for various B contents.

as open circles, was shifted to higher angle as the B contents increased. Figure 4 shows the change of FeCo (110) lattice spacing as a function of the B content. Higher B content caused decrease of FeCo (110) lattice spacing along the normal direction of the film plane. This result implied that B additions cause contraction of FeCo (110) lattice to perpendicular direction.

Figure 5 shows the variation of in-plane XRD diagrams of (110) lattice plane observed along the easy and hard axis directions. The solid and the dashed line circles correspond to the diffraction peaks to detect interplanar distances of the lattice plane along the easy and hard axis directions, respectively, of Ru/$(Fe_{70}Co_{30})_{100-x}B_x$ layers. The diffraction peak positions for the hard axis directions are always higher than that for the easy axis directions. The peak positions varied toward lower diffraction angles as the B content increases up to 10 at.%. Figure 6 shows

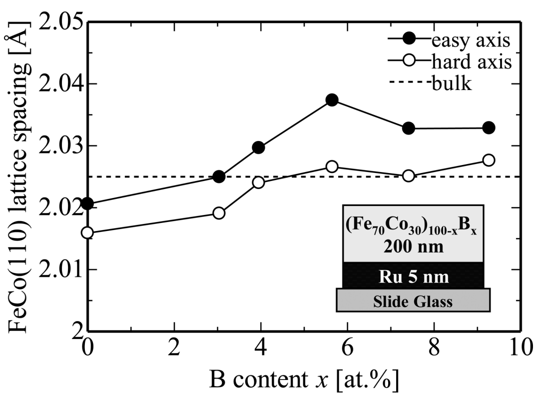

Fig. 6. Changes of FeCo (110) lattice spacing along the easy and the hard axis directions as a function of B content.

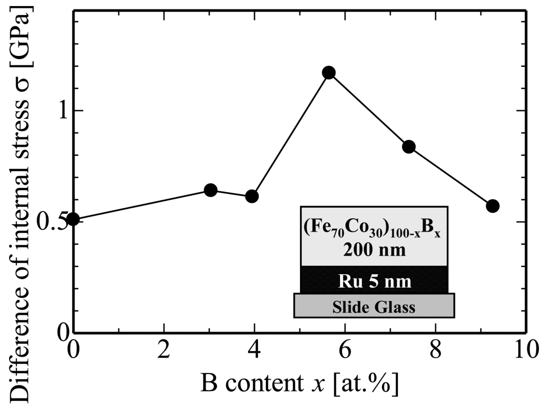

Fig. 7. Difference of internal stress s of Ru/$(Fe_{70}Co_{30})_{100-x}B_x$ layers as a function of B content.

the changes of FeCo (110) lattice spacing along the easy and the hard axis as a function of B content. The expansion of FeCo (110) lattice according to easy and hard axis direction compensates the contraction of FeCo (110) lattice in perpendicular direction which is observed in Fig. 4. Figure 7 shows the estimated differences of residual internal stress σ of Ru/$(Fe_{70}Co_{30})_{100-x}B_x$ films along easy and hard axis direction as a function of the B content. The difference of the in-plane residual internal stresses along the easy and the hard axis directions ó were estimated using following equation:

$$\sigma = \sigma_{easy} - \sigma_{hard} = \varepsilon \frac{d_{easy} - d_{hard}}{d_0} \quad (1)$$

where ε and d_0 are a Young's modulus and a bulk value of the (110) lattice spacing of FeCo crystal, respectively. Relatively large residual internal stress σ was observed at B content around 6%. This result implied that an appropriate amount of B in the film plays an important role to fix the lattice distortion of the FeCoB crystallites which may be caused by the oblique incidence of sputtered particles to the substrate with its incident direction parallel along the easy axis of the film [1]. Such a high distortion causes an anisotropic stress resulting in the origin of the high H_k [3]. Further addition of B causes decrease of in-plane FeCo(110) lattice spacing which degrades the H_k. Anisotropy field H_k and can be estimated as a result of the inverse magnetostrictive effect originated from the in-plane anisotropic residual stress σ. Estimated H_k are also plotted as open circles in Fig. 2. The measured and the estimated values of H_k are in good agreement as a function of the B content. Additions of B seem to play an important role in fixing the differences of lattice distortion along the easy and the hard axis directions.

Figure 8 shows the frequency response of the real and

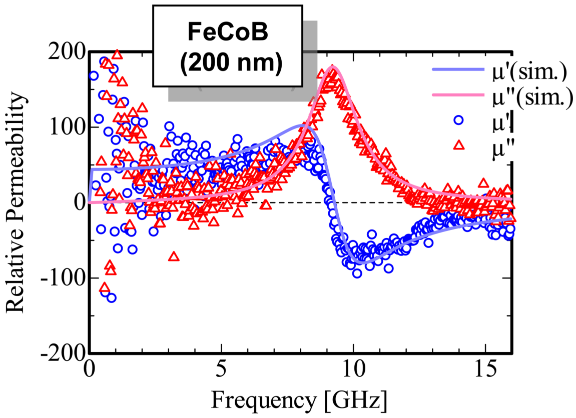

Fig. 8. (Color online) Changes of relative permeability of FeCoB films as a function of frequency.

imaginary parts of complex relative permeability of the FeCoB film prepared from FeCoB targets with B content of 6 at.%. The film possesses an anisotropy field H_k of 500 Oe. The experimental results are in good agreement of the simulated results using the values of $4\pi M_s$ and H_k of 22 kG and 500 Oe, respectively. The f_r of the film indicates 9.2 GHz.

4. Conclusion

The effect of B additions in Ru/FeCoB film on the crystallographic characteristics and in-plane magnetic anisotropy field H_k were investigated. Increases of B content causes compression of FeCo (110) lattice along the perpendicular direction and the expansion of the lattice to in-plane direction. The difference of the lattice constants along the easy and the hard axis were observed in the films with B content from 0 to 10 at.%, which indicates the differences of the residual stress along the two directions. The differences of the residual stress took maximum at appropriate B content around 6 at.%. Such a difference of the residual stress of distortion of the lattice seems to be the origin of high H_k. The measured and the estimated values of H_k are in good agreements as a function of B content.

References

[1] A. Hashimoto, K. Hirata, T. Matsuu, S. Saito, and S. Nakagawa, IEEE Trans. Magn. **44**, 3899 (2008).
[2] K. Hirata, S. Gomi, and S. Nakagawa, J. Nanosci. Nanotechnol. **11**, 2739 (2011).
[3] K. Hirata, S. Gomi, Y. Mashiko, and S. Nakagawa, J. Appl. Phy. **107**, 09A323 (2009).