Evaluation of Magnetization Interaction at the Interface between FeCo and TbFeCo for p-MTJ

N. Miyamoto, K. Mamiya and S. Nakagawa
Department of Physical Electronics, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro, Tokyo, 152-8552, Japan
E-mail: nakagawa@pe.titech.ac.jp

Abstract. Magnetic interaction at the interface between FeCo and TbFeCo were investigated to improve perpendicular magnetic tunnel junction. Magnetic properties of TbFeCo/thin and thick FeCo were observed by anomalous Hall effect (AHE). A perpendicular component of magnetization of thin FeCo layer adjacent to TbFeCo layer was larger than that of thick FeCo one. Kerr hysteresis observation clarified the magnetization behavior of the region of the TbFeCo layer adjacent to FeCo layer using the characteristic of a penetration depth of the probe light. The TbFeCo layer attached with thinner FeCo layer was saturated at lower applied field than that with thicker one. This suggested that the magnetization of FeCo layer affected the TbFeCo magnetization and the thicker FeCo layer tilts the TbFeCo magnetization more greatly than thinner one.

1. Introduction
Perpendicular magnetic tunnel junctions (p-MTJs) are promising candidates for magnetoresistive random access memory (MRAM) with high integration and low power consumption [1][2]. There are various perpendicular magnetization films such as $L1_0$-FePt(001) ordering thin films and Co/Pt multilayers [3][4][5], however we have studied p-MTJs with Rare Earth-Transition Metal (RE-TM) alloy films, and obtained 64% tunnel magnetoresistance (TMR) ratio at room temperature [6]. In this p-MTJ structure, highly magnetically polarized layer, such as FeCo layer, should be inserted at the interface of the tunnel barrier in MTJ structure in order to obtain high TMR ratio. In addition, the FeCo polarized layer should be magnetized perpendicularly to the interface plane by exchange coupling with RE-TM alloy films for practical application of this p-MTJ. Therefore, it is important to evaluate coupling of the magnetizations at the interface between FeCo and RE-TM alloy films. In this study, such magnetic interactions between FeCo and RE-TM alloy films were not only clarified by anomalous Hall effect (AHE) and Kerr effect, but also the useful method of measuring the magnetization state by Kerr effect was reported.

2. Experimental
All specimen films were prepared on glass substrates at ambient temperature by ion beam sputtering. Fe$_{70}$Co$_{30}$, Tb$_{26}$(Fe$_{90}$Co$_{10}$)$_{74}$ and Ta were used as targets in this study. Ta layers were prepared to avoid oxidation of specimens and adjust intrusion length of Kerr probe light as discussed later. Magnetic properties were observed by anomalous Hall effect (AHE) and polar Kerr effect. The AHE output voltage $V_{AHE}$ which is proportional to the perpendicular magnetization component of a film is given by,
\[ V_{\text{AHE}} = \left( \frac{\mu_0 R_s I}{t} \right) M \cos \theta \]  

In the above equation, \( \mu_0 \), \( R_s \), \( t \) and \( I \) are permeability of vacuum, Hall resistivity, film thickness and current, respectively. \( M \) and \( \theta \) are the magnetization and its angle from the normal of the film plane, respectively [7].

3. Results and discussions

3.1. Magnetization states observed by Hall effect

Figure 1 shows the magnetic properties of TbFeCo(50 nm)/FeCo(\( X \) nm)/Ta(15 nm) film, where the magnetic field was applied perpendicularly to the film plane with different FeCo layer thickness \( X \). The specimen with 0.6 nm thickness FeCo is saturated at lower applied field than that with 2 nm thickness one. This indicates that a tilt of magnetization in the thinner FeCo layer is less than that of magnetization in the thicker FeCo one as shown in Figure 2. Since an exchange coupling originates just at the interface between FeCo and TbFeCo layers, the upper part of the thick FeCo layer, where the region is far from the interface, is regarded that the magnetization in the region is more tilted than that in the bottom part of the region near the interface between the two layers as shown in Figure 2.

3.2. Determination of the penetration length of Kerr probe light

The magnetization state of the interface between FeCo and TbFeCo cannot be fully understood by the observation of AHE loops, thus Kerr hysteresis analysis was chosen to clarify the magnetization of TbFeCo layer at the region near the FeCo layers. Magnetic properties where probe light reaches can be observed by Kerr effect, therefore penetration length of the probe light should be estimated. Figure 3 shows magnetic properties of TbFeCo(50 nm)/Ta(\( X \) nm) film with various layer thickness \( X \) of Ta by Kerr observation. In the case of \( X = 40 \) and 42 nm, typical hysteresis loops of perpendicularly magnetized films can be obtained from the TbFeCo layer beneath the Ta layers. However, these hysteresis loops ware not shown and just a loop derived from paramagnetic was observed when the thickness of Ta was 45 nm. This indicates that Kerr probe light can pass through 42 nm in Ta layer and reach TbFeCo layer. This means that the probe light cannot pass through more than 42 nm of Ta layer. Therefore intrusion length of Kerr probe light is estimated as 42 nm in this study.
3.3. Observation of magnetization states at the interface between FeCo and TbFeCo

In order to evaluate magnetization states of the interface between FeCo and TbFeCo by Kerr hysteresis loops, FeCo(\(X\) nm)/TbFeCo(30 nm)/Ta(15 nm) films with various FeCo film thickness were prepared. Here the deposition order of TbFeCo and FeCo was changed in order to observe mainly TbFeCo magnetic characteristics. Supposing that the intrusion length of the Kerr probe light is 42 nm, Figure 4 shows magnetic properties of TbFeCo around the interface between FeCo and TbFeCo of FeCo(\(X\) nm)/TbFeCo(30 nm)/Ta(15 nm) films. The difference of magnetization characteristics of the two hysteresis loops is regarded as the difference of the magnetization behaviour of the region of the TbFeCo layer near the interface between FeCo and TbFeCo, since the penetration of the probe light detects only the region of the TbFeCo layer. Outputs of each loop increase as increasing applied field, since magnetization of TbFeCo are tilted. However the specimen with thinner FeCo layer was saturated at lower applied field of 10 kOe than that with thicker one. Figure 5 shows the change of \(\frac{d\theta}{dH}\) as a function of applied field \(H\). The decrease of \(\frac{d\theta}{dH}\) can be recognized around 10 kOe in the specimen with 0.6 nm thickness FeCo layer. This indicates that the magnetization of FeCo layer affects the magnetization of TbFeCo at the interface between FeCo and TbFeCo as shown in Figure 6. Thicker FeCo layer tilts the magnetization of TbFeCo more greatly than the thinner one.

![Figure 3. Kerr hysteresis loops of TbFeCo(50 nm)/Ta(\(X\) nm) films with different Ta layer thickness.](image)

![Figure 4. Kerr hysteresis loops of FeCo(\(X\) nm)/TbFeCo(30 nm)/Ta(15 nm) films with different FeCo layer thickness.](image)

![Figure 5. \(d\theta / dH\) of FeCo(\(X\) nm)/TbFeCo(30 nm)/Ta(15 nm) films observed by Kerr effect.](image)
4. Conclusion

Magnetization states of the region around the interface between FeCo and TbFeCo layers in the FeCo/TbFeCo bilayers were investigated. Magnetic properties of TbFeCo/thinner and thicker FeCo/Ta were observed by AHE. It was found that a tilt of magnetization of thinner FeCo layer is less than that of magnetization of thicker FeCo one. Kerr hysteresis observation clarified that the specimen with thinner FeCo layer can be saturated at lower applied field than that with thicker one. This suggested that FeCo layer affected the TbFeCo magnetization at the interface between FeCo and TbFeCo and thicker FeCo layer tilted the TbFeCo magnetization more greatly than thinner one.

5. References

[1] N. Nishimura, T. Hirai, A. Koganei, T. Ikeda, K. Okano, Y. Sekiguchi and Y. Osada, *J. Appl. Phys.* **91**(8), 5246 (2002)
[2] S. Mangin, D. Ravelosona, J. A. Katine, M. J. Carey, B. D. Terris and E. E. Fullerton, *Nature Mater.* **5**, 210-215 (2006)
[3] M. Yoshikawa, E. Kitagawa, T. Nagase, T. Daibou, M. Nagamine, K. Nishiyama, T. Kishi and H. Yoda, *IEEE Trans. Magn.* **44**(11), 2573 (2008)
[4] C. Ducruet, B. Carvello, B. Rodmacq, S. Auffret, G. Gaudin and B. Dieny, *J. Appl. Phys.* **103**, 07A917 (2008)
[5] J.-H. Park, C. Park, T. Jeong, M. T. Moneck, N. T. Nufer and J.-G. Zhu, *J. Appl. Phys.* **103**, 07A917 (2008)
[6] H. Ohmori, T. Hatori, and S. Nakagawa, *J. Appl. Phys.* **103**, 07A911 (2008)
[7] E. M. Pugh, N. Rostoker, *Rev. of modern phys.* **25**, 151, (1953)