Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp956-957

# Magnetic Sensors Based on MgO-Magnetic Tunnel Junctions with Perpendicularly Magnetized CoFeB Sensing Layers

Takafumi Nakano[1], Mikihiko Oogane[1], Hiroshi Naganuma[1], Toshifumi Yano[2], Kenichi Ao[2], and Yasuo Ando[1]

[1] Tohoku Univ.
Department of Applied Physics
6-6-05 Aoba, Aramakiaza, Aoba-ku, Sendai, Miyagi, 980-8579, Japan
Phone: +81-022-795-7949 E-mail: Takafumi_Nakano@mlab.apph.tohoku.ac.jp
[2] DENSO Corp.
Department of Semiconductor Process Development
1-1, Syowamachi, Kariya, Aichi, 448-8661, Japan

**Abstract**

**We fabricated magnetic sensors exhibiting linear magneto-resistance by using a perpendicularly magnetized CoFeB sensing layer. The sensing response apparently depends on the thickness of the CoFeB sensing layers since its perpendicular magnetic anisotropy critically correlates to the thickness and annealing temperature.**

## 1. Introduction

Spin valves and magnetic tunnel junctions (MTJs) have been widely investigated for the application to magnetic sensors because of their high sensitivity, low power consumption, and micro size[1][2]. In order to achieve a linear and reversible response to a magnetic field, it is one popular method to align a magnetization of a sensing layer and a reference layer to be perpendicular to each other. This cross configuration is obtained by utilizing perpendicular magnetic anisotropy (PMA) materials[3][4][5]. High tunnel magneto-resistance (TMR) ratio is desirable for high sensitivity and PMA is necessary for the linear response. In addition, the tunability of the PMA allows us to easily control sensing properties. Recently, CoFeB electrodes for MgO-based MTJs have been an attractive material exhibiting TMR ratio and large PMA[6][7][8]. Perpendicularly magnetized CoFeB is a promising material for magnetic sensors. In this study, we demonstrated the linear magneto-resistive response of magnetic sensors based on an MTJ with a perpendicularly magnetized CoFeB sensing layer.

## 2. Experiments

The stack-structure was Si,$SiO_2$-substrate/Ta (5)/Ru (10)/$Ir_{22}Mn_{78}$ (10)/$Co_{75}Fe_{25}$ (2)/Ru (0.85)/ $Co_{40}Fe_{40}B_{20}$ (3)/MgO (1.3)/$Co_{40}Fe_{40}B_{20}$ ($t_{CoFeB}$)/Ta (5)/Ru (8) (in nm), deposited by the DC/RF magnetron sputtering. We varied the thickness of the CoFeB sensing layer ($t_{CoFeB}$) from 1.2 to 1.6 nm to tune its PMA. The MTJs of 80 x 40 to 20 x 10 $\mu m^2$ were fabricated by 1 inch photolithography and Ar ion milling process. 1-h-post-annealing processes were performed in a vacuum at the varying temperature from 275 to 375°C under the magnetic field of 1 T. We evaluated the transport property by DC four-probe-method.

## 3. Results and Discussions

Figures 1 (a)-(c) show the TMR ratio as a function of an applied magnetic field for the MTJs annealed at 300 °C with the different thickness of the sensing layer. For the MTJ with $t_{CoFeB}$ = 1.6 nm, typical TMR curve was observed and its TMR ratio [($R_{AP}$-$R_P$)/$R_P$, where $R_{AP}$ and $R_P$ are the resistances for the anti-parallel and parallel alignment of the magnetization, respectively] was 161 %. This indicates the magnetization of the CoFeB sensing layer was in-plane.

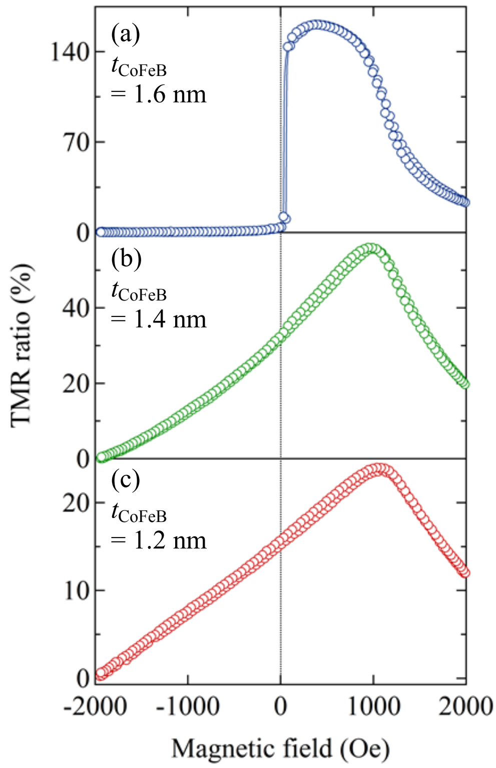


Fig. 1 (a)-(c) TMR curves for the MTJs annealed at 300 °C with the different thickness of the sensing layer.

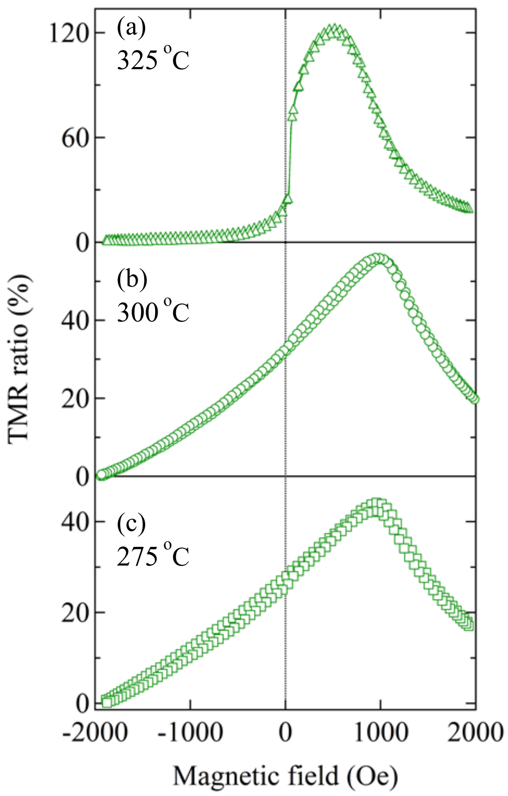


Fig. 2 (a)-(c) TMR curves for the MTJs with the CoFeB sensing layer of $t_{CoFeB}$ = 1.4 nm for the different annealing temperature.

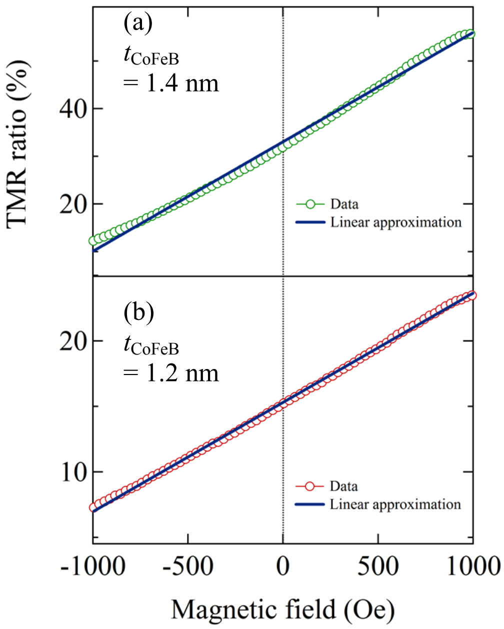


Fig. 3 (a), (b) TMR curves in the linear field range for the MTJs annealed at 300 °C with the CoFeB sensing layer of $t_{CoFeB}$ = 1.2 nm and 1.4 nm, respectively.

With decreasing $t_{CoFeB}$, its PMA increased, and the linear resistive response was observed for $t_{CoFeB}$ of 1.2 and 1.4 nm. In these MTJs, the perpendicular configuration of the easy axis between the sensing layer and the reference layer was obtained.

Figures 2 (a)-(c) show the TMR curves for the MTJs with the CoFeB sensing layer of $t_{CoFeB}$ = 1.4 nm. With increasing the annealing temperature, the PMA of CoFeB decreased. This correlates to the change of the interfacial structure of MgO/CoFeB due to the annealing. The linear field range disappeared at more than 325 °C. The MTJs with $t_{CoFeB}$ = 1.2 nm showed the same behavior.

Figures 3 (a), (b) show the TMR curves in the linear field range for the MTJs annealed at 300 °C. The circle is the measured data and the line is calculated by the linear approximation. The sensing properties were evaluated in the range between -1000 and 1000 Oe. We obtained the sensitivity of 0.0085 and 0.025 %/Oe, the linearity of 2.0 and 4.9% for $t_{CoFeB}$ = 1.2 and 1.4 nm, respectively. Here, the sensitivity is the value of TMR ratio divided by the field sensing range, and the linearity is the normalized difference between the measured TMR ratio and the linear fit. The sensitivity of 0.025 %/Oe is significantly larger than that in previously reported magnetic sensors (0.0018 %/Oe) with perpendicularly magnetized sensing layers[3]. This is due to the larger TMR ratio with MgO-based MTJs.

## 4. Summary

We demonstrated the linear response of the magnetic sensors based on MgO-MTJs with the perpendicularly magnetized CoFeB sensing layer. The cross configuration of the magnetizations was achieved and the linear TMR curves were observed for the sensing layers of 1.2 and 1.4 nm. The sensitivity and the linearity were evaluated as 0.025 %/Oe and 4.9 % for $t_{CoFeB}$ = 1.4 nm, respectively. The sensing properties depend significantly on the thickness of the sensing layers and the annealing temperature.

## References

[1] K. Fujiwara, M. Oogane, T. Nishikawa, H. Naganuma, and Y. Ando, Jpn. J. Appl. Phys. 52, 04CM07 (2013).
[2] D. Kato, M. Oogane, K. Fujiwara, T. Nishikawa, H. Naganuma, and Y. Ando, Appl. Phys. Express **6**, 103004 (2013).
[3] Y. Ding, J. H. Judy, and J. Wang, J. Appl. Phys. **97**, 10N704 (2005).
[4] S. Van Dijken and J. M. D. Coey, Appl. Phys. Lett. **87**, 022504 (2005).
[5] Z. M. Zeng, P. Khalili Amiri, J. A. Katine, K. L. Wang, and H. W. Jiang, Appl. Phys. Lett. **101**, 062412 (2012).
[6] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki and K. Ando, Nature Mater. **3**, 868 (2004).
[7] S. Ikeda, J. Hayakawa, Y. Ashizawa, Y, M. Lee, K. Miura, H. Hasegawa, F. Matsukura and H. Ohno, Appl. Phys. Lett. **93**, 082508 (2008).
[8] S. Ikeda, K. Miura, H. Yamamoto, K. Mizunuma, H. D. Gan , M. Endo, S. Kanai, J. Hayakawa, F. Matsukura and H. Ohno, Nature. Mater. **9**, 721 (2010).