Controlling nonlinearity for magnetic tunnel junction based sensors by second order magnetic anisotropy of CoFeB

Takahiro Ogasawara[1], Mikihiko Oogane[1,2,3], Masakiyo Tsunoda[3,4], and Yasuo Ando[1,2,3]
[1]Department of Applied Physics, Tohoku University, Sendai 980-8579, Japan
[2]Center for Science and Innovation in Spintronics (Core Research Cluster) Organization for Advanced Studies, Tohoku University, Sendai 980-8577, Japan
[3]Center for Spintronics Research Network, Tohoku University, Sendai 980-8577, Japan
[4]Department of Electronic Engineering, Tohoku University, Sendai 980-8579, Japan

An achievement of high tunnel magnetoresistance (TMR) ratio [1] has enabled to develop highly sensitive magnetic sensors using magnetic tunnel junctions (MTJs) [2]. On their electric vehicle applications for current monitoring, the linear output, *i.e.* low nonlinearity should be achieved for safe operations. However, previously, sensitivity and nonlinearity were reported to be in the trade-off relationship as a function of effective anisotropy field, H_k^{eff}, and it thus results in a lack of either of them by controlling H_k^{eff} [3]. Therefore, in order to break this restricted relationship, we focused on second order anisotropy field, H_{k2} and established a new approach for decreasing nonlinearity while achieving a high sensitivity simultaneously.

The MTJs with Ta/Ru/Pt/[Co/Pt]/Ru/[Co/Pt]/CoFeB(1)/MgO(2)/CoFeB(1.5-2.0)/Ta/Ru (thickness in nm) were deposited on SiO_2 substrate by dc/rf sputtering at room temperature. After pattering them into the circular junctions and post annealing at 300°C, TMR curves were measured by four-probe-method at 50 - 400 K using probe station and PPMS. For the magnetic characterization of the free CoFeB layer, Ta/MgO/CoFeB/Ta films were prepared separately by the same method. The effective and second anisotropy field, H_k^{eff}, H_{k2} and saturation magnetization, M_s were measured by angular-dependent FMR and SQUID, respectively.

Fig. 1 shows conductance ratio curve for the MTJ with 1.5-nm-thick CoFeB. The jump of the curve at ±4 kOe corresponds to the large antiferromagnetic coupling field of [Co/Pt] via Ru. The linear output within ±2 kOe is due to the rotation of in-plane magnetized free layer CoFeB, where its H_k^{eff} and H_{k2} were measured to be -1.7 kOe and 0.4 kOe, respectively by FMR. The nonlinearity was evaluated by the equation of $(G_{exp}-G_{fit})/(G_{exp}^{max}-G_{exp}^{min})\times 100$ (%), which quantifies the normalized differences between experimental and linear-fitted conductance, G_{exp} and G_{fit}. As shown in Fig. 2 summarizing the maximum nonlinearity against H_{k2}/H_k^{eff}, the experimental results coincide very well with the calculations using simultaneous rotation and Slonczewski's TMR model. Therefore, we succeeded in establishing the new approach to describe the nonlinearity quantitatively with second order magnetic anisotropy, which is greatly useful for diminishing nonlinearity of MTJ sensors.

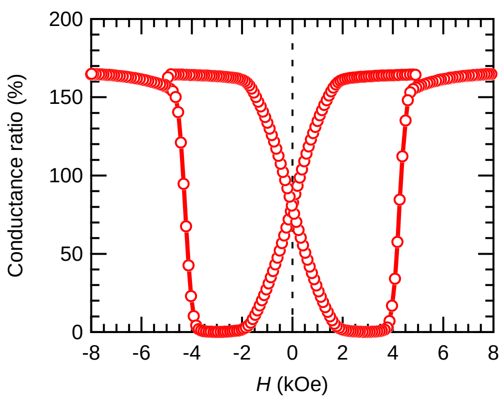

Fig. 1 Out-of-plane conductance ratio curve for MTJ with 1.5nm-thick-CoFeB free layer

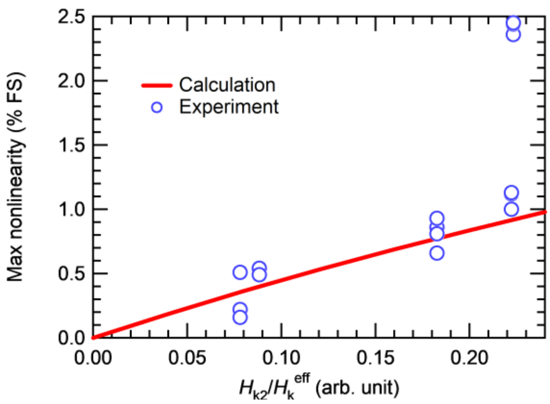

Fig. 2 Maximum nonlinearity dependence on H_{k2}/H_k^{eff}

Reference

[1] S. Yuasa, et al, Nat. Mater. 3, 868 (2004). [2] K. Fujiwara, M. Oogane, Y. Ando et al., Appl. Phys. Express 11 023001 (2018). [3] T. Nakano, M. Oogane, T. Furuichi, and Y. Ando. Appl. Phys. Lett. 110, 012401 (2017)