Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp318-319

In-plane Anisotropy of a CoFeB-MgO Magnetic Tunnel Junction with Perpendicular Magnetic Easy Axis

E. Hirayama[1],
S. Kanai[1], K. Sato[2], M. Yamanouchi[1,3], H. Sato[3,4], S. Ikeda[1,3,4], F. Matsukura[2,3] and H. Ohno[1-4]

[1] Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai, Miyagi, 980-8577, Japan
Phone: +81-22-217-5555 E-mail: eriko04@riec.tohoku.ac.jp
[2] WPI-Advanced Institute for Materials Research, Tohoku University
2-1-1, Katahira, Aoba-ku, Sendai, Miyagi, 980-8577, Japan
[3] Center for Spintronics Integrated Systems, Tohoku University
2-1-1, Katahira, Aoba-ku, Sendai, Miyagi, 980-8577, Japan
[4] Center for Innovative Integrated Electronic Systems, Tohoku University
468-1, Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi, 980-0845, Japan

Abstract

We investigate magnetic properties of a 100 nm-diameter CoFeB-MgO magnetic tunnel junction with perpendicular magnetic easy axis. We measure the in-plane magnetic field angle dependence of homodyne detected ferromagnetic resonance (FMR) spectra and junction resistance. The obtained resonant frequency of FMR is anisotropic in its in-plane angle dependence. The in-plane anisotropy is observed also in resistance versus magnetic field curves.

1. Introduction

CoFeB-MgO magnetic tunnel junctions (MTJs) with perpendicular magnetic easy axis are important building blocks for high performance non-volatile memory and spintronics-based VLSI [1]. It is important to establish evaluation methods of magnetic properties in nanoscale MTJs for further understanding and improvement of their characteristics. In this work, homodyne detected ferromagnetic resonance (FMR) and junction resistance R are utilized to characterize magnetic properties of a nanoscale MTJ with perpendicular magnetic easy axis [2,3].

2. Experimental

A stack structure, Ta(5)/ Pt(5)/ [Co(0.4)/ Pt(0.4)]$_6$/ Co(0.4)/ Ru(0.42)/ [Co(0.4)/ Pt(0.4)]$_2$/ Co(0.4)/ Ta(0.3)/ $Co_{18.75}Fe_{56.25}B_{25}$(1)/ MgO(1.3)/ $Co_{18.75}Fe_{56.25}B_{25}$(1.8)/ Ta(5)/ Ru(5) (numbers in parenthesis are nominal thickness in nanometers), is deposited by dc/rf magnetron sputtering. The stack is processed into a circular MTJ with 100 nm diameter on a coplanar waveguide by electron beam lithography and Ar ion milling. The MTJ is annealed at 300°C in vacuum (10^{-6} Torr) for 1 hour. The two CoFeB layers have perpendicular magnetic easy axis, and the top layer is the free layer. Synthetic ferrimagnetic (SyF) structure is adopted as a reference layer to suppress stray field acting on the free layer. Tunnel magnetoresistance ratio and resistance-area product are 84% and 13 $\Omega\mu m^2$, respectively. The magnetization configuration at zero magnetic field is set to antiparallel configuration. By sweeping frequency f of rf signal with power of -25 dBm, FMR spectra are measured by dc component of reflected voltage as a function of the angle ϕ_H of in-plane magnetic field H_{in}, where ϕ_H is measured from the direction along coplanar wave guide. We measure R as a function of ϕ_H by sweeping the amplitude of H_{in}.

3. Results

Figure 1 shows FMR spectra at various ϕ_H from 0° to 360° with 30° step under $\mu_0 H_{in}$ = 100 mT, where μ_0 is the permeability of free space. The spectra show anti-symmetric Lorentzian lineshape, indicating that the FMR is induced by electric field-modulation of magnetic anisotropy and/or field-like-torque in the MTJ [4]. The resonant

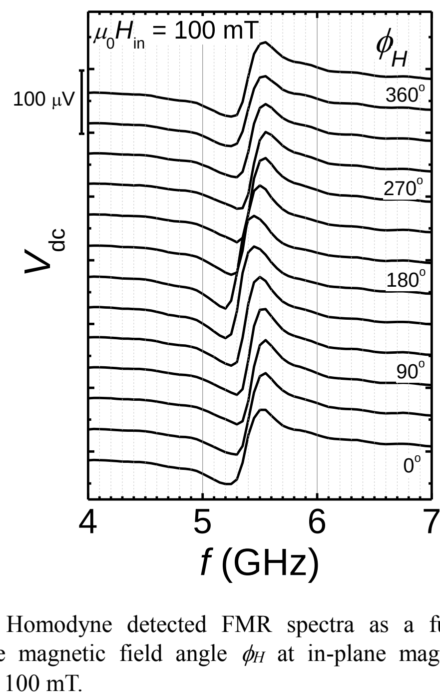

Fig. 1 Homodyne detected FMR spectra as a function of in-plane magnetic field angle ϕ_H at in-plane magnetic field $\mu_0 H_{in}$ = 100 mT.

frequency f_r takes different value at different ϕ_H, and its variation is about 0.1 GHz, suggesting the presence of in-plane anisotropy in the device.

To confirm the presence of the anisotropy, we measure R-H_{in} curves as a function of ϕ_H. Figure 2 shows a typical R-H_{in} curve obtained at ϕ_H = 0°. The change of R reflects the change of the relative angle θ between the magnetizations in the two CoFeB layers. We observe slightly different shape of R-H_{in} at different ϕ_H (not shown), which indicates that the effective anisotropy field H_{K1}^{eff} depends on ϕ_H. We analyze R-H_{in} curves by using the energy minimum condition of magnetostatic energy as well as the relationship between R and θ, and obtain the ϕ_H dependence of H_{K1}^{eff} in the free layer. The dependence possesses two-fold symmetry, showing that the origin of the dependence is related to the shape anisotropy of the device. The ϕ_H dependence of f_r is explained by substituting H_{K1}^{eff} into resonant condition for FMR. The results indicate that both FMR and R-H_{in} measurements are useful to evaluate magnetic properties of MTJs at reduced dimensions.

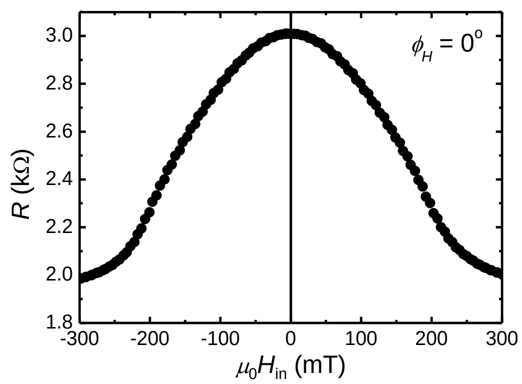

Fig. 2 In-plane magnetic field dependence of junction resistance R at ϕ_H = 0°.

4. Conclusion

We measure the in-plane magnetic field angle dependence of homodyne detected FMR spectra and junction resistance of the CoFeB-MgO MTJs with SyF reference layer. We find that resonant frequency of FMR and shapes of junction resistance versus magnetic field curves depend on the in-plane magnetic field direction, which is explained by the angle dependent effective magnetic anisotropy in the device.

Acknowledgements

The authors thank to K. Mizunuma, T. Hirata, H. Iwanuma, C. Igarashi, Y. Iwami and I. Morita for their technical supports and discussion. This work was supported in part by JSPS through FIRST program, R&D for Next-Generation Information Technology of MEXT, and Grand-in-Aid for JSPS Fellows.

References

[1] 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** (2010) 721.

[2] A. A. Tulapurkar, Y. Suzuki, A. Fukushima, H. Kubota, H. Maehara, K. Tsunekawa, D. D. Djayaprawira, N. Watanabe and S. Yuasa, Nature (London) **438** (2005) 339.

[3] K. Mizunuma, M. Yamanouchi, H. Sato, S. Ikeda, S. Kanai, F. Matsukura and H. Ohno, Appl. Phys. Express **6** (2013) 063002.

[4] T. Nozaki, Y. Shiota, S. Miwa, S. Murakami, F. Bonell, S. Ishibashi, H. Kubota, K. Yakushiji, T. Saruya, A. Fukushima, S. Yuasa, T. Shinjo and Y. Suzuki, Nat. Phys. **8** (2012) 492.