Temperature dependence of relaxation time of superparamagenetic tunnel junctions

○(B)Haruna Kaneko,[1,2] (M1)Rikuto Ota,[1,3] (M2)Keito Kobayashi,[1,3] Shun Kanai,[1,3-7] Hideo Ohno,[1,3,6,7,8] and Shunsuke Fukami[1,3,6-9]

[1]Laboratory for Nanoelectronics and Spintronics, RIEC, Tohoku Univ., [2]School of Engineering, Tohoku Univ., [3]Graduate School of Engineering, Tohoku Univ., [4]JST PRESTO, [5]DEFS, Tohoku Univ., [6]CSIS, Tohoku Univ., [7]WPI-AIMR, Tohoku Univ., [8]CIES, Tohoku Univ., [9]InaRIS

E-mail: haruna.kaneko.t3@dc.tohoku.ac.jp

Superparamagnetic tunnel junctions (s-MTJs) are gathering attention as a key element for probabilistic computers [1-4]. The temperature dependence of the s-MTJ properties is of importance because the stability of their bit states changes with the operation temperature, affecting the computation performance. In this work, we investigate the relaxation time of the s-MTJs at different temperatures.

A stack structure, Ta (5)/ Pt (5)/ [Co (0.4)/ Pt (0.4)]$_{6.5}$/ Ru(0.4)/ [Co (0.4)/ Pt (0.4)]$_{2.5}$/ Ta (0.2)/ CoFeB (1.0)/ MgO (1.1)/ CoFeB (1.5)/ Ta (5)/ Ru (5) (thickness in nm), is deposited by dc/rf magnetron sputtering. Both the bottom and top CoFeB layers show a perpendicular easy axis. The stacks are processed into circular MTJs by electron beam lithography and Ar ion milling and annealed at 300°C for 1 hour. The typical tunnel magnetoresistance ratio and the resistance area product are 77% and 11 Ωμm^2, respectively. The magnetic moment of the bottom CoFeB is fixed by the synthetic ferrimagnetic multilayers, and the magnetic moment of the top CoFeB layer is designed to fluctuate at room temperature.

We measure rf transmitted voltage and the time-averaged (dc) resistance $\langle R \rangle$ of the s-MTJs at measurement temperatures 20°C ≤ T ≤ 120°C and perpendicular magnetic field H_z. By the rf transmitted voltage, we determine the relaxation time τ_{ave} [3]. Three typical s-MTJs with diameters D ~ 20 nm showing τ_{ave} of ~100 ms at room temperature are studied. With the increase of T, τ_{ave} decreases and reaches ~10 μs at T = 120°C. Following Refs. [5] and [6], we determine the attempt time τ_0 and thermal stability factor Δ of the s-MTJs at each T from τ_{ave} and the slope of $\langle R \rangle$ *vs*. H_z. Contrary to the standard Arrhenius model with a constant τ_0, we find that, in addition to Δ, τ_0 varies with increasing T.

This work was supported in part by the JST-CREST Grant No. JPMJCR19K3, the JST-PRESTO Grant No. JPMJPR21B2, JSPS Kakenhi Grant Nos. 19H05622, 19KK0130, and 20H02178, Shimadzu Research Foundation, Takano Research Foundation, and Cooperative Research Projects of RIEC.

References

[1] K. Y. Camsari *et al*., Phys. Rev. X **7**, 031014 (2017). [2] W. A. Borders *et al*., Nature **573**, 390 (2019).
[3] K. Hayakawa *et al*., Phys. Rev. Lett. **126**, 117202 (2021). [4] T. Funatsu *et al*., Nat. Commun. **13**, 4079 (2022).
[5] K. Kobayashi *et al*., Appl. Phys. Lett. **119**, 132406 (2021). [6] W. F. Brown, Phys. Rev. **130**, 1677 (1963).