Relaxation time of in-plane stochastic magnetic tunnel junctions

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Stochastic magnetic tunnel junctions (MTJs) have gathered much attention as a promising building block for probabilistic computing. Integer factorization has been demonstrated with stochastic MTJs with a perpendicular easy axis (p-MTJs) and milliseconds-long relaxation time τ [1]. In contrast, τ of in-plane easy-axis MTJs (i-MTJs) is reported to be down to sub-microseconds [2]. Here, we study the mechanism governing the different timescale of τ in stochastic MTJs.

We deposit a stack, Ta (5.0)/ PtMn (20)/ Co (2.6)/ Ru (0.90)/ CoFeB (2.4)/ MgO/ CoFeB (2.1)/ Ta (5.0)/ Ru (5.0) (thickness in nm), on a thermally oxidized Si substrate by dc/rf magnetron sputtering. Both bottom (reference) and top (free) CoFeB layers have an in-plane easy axis, and the top layer has an effective perpendicular anisotropy field $\mu_0 H_K^{\mathrm{eff}}$ of –0.46 T. Samples are processed into elliptic MTJs with geometry averaged diameter of 55 nm. The typical tunnel magnetoresistance ratio of the devices is 110% and resistance area product is 32 $\Omega\mu\mathrm{m}^2$. The time-averaged resistance as a function of an in-plane magnetic field along the long axis of MTJs indicates superparamagnetic behavior of the MTJ with zero coercivity. We measure random telegraph noise and obtain τ averaged for P and AP states of 19 ns, which is two orders shorter than that ever demonstrated in i-MTJs.

We then simulate τ of p- and i-MTJs with stochastic Landau-Lifshitz-Gilbert (LLG) equation. We assume $\mu_0 H_K^{\mathrm{eff}} = 10$ mT, damping constant $\alpha = 0.02$, and thermal stability factor $\Delta = 3.8$ for p-MTJ, and $\mu_0 H_K^{\mathrm{eff}} = -0.46$ T, in-plane anisotropy field $\mu_0 H_{K,\mathrm{in}} = 10$ mT, $\alpha = 0.02$, and $\Delta = 3.8$ for i-MTJ. We find that despite systems that have the same Δ, τ for the p- and i-MTJ are about 40 times different, *i.e.*, τ in p-MTJ is 0.8 μs, while that for i-MTJ is 20 ns. Probability density evolution based on Fokker-Planck equation [3] reveals that the different timescale of τ obtained here can be attributed to the difference of the precessional frequency due to the different potential landscape, and suggests that i-MTJs with $\mu_0 |H_K^{\mathrm{eff}}| \sim 1$ T can achieve τ down to nanoseconds.

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References

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