# Write-error rate of perpendicular-anisotropy CoFeB/MgO-based magnetic tunnel junction with different junction diameters

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Write-error rate (WER) is one of the important properties characterizing a magnetic tunnel junction to be used in integrated circuits. It was reported that domain wall (DW) pinning during STT-induced switching was observed at certain probability in large MTJs [1]. Because the stochastic nature of the DW pinning and depinning disturbs switching, it could affect WER. In this study, we investigate WER in CoFeB/MgO based MTJs with a perpendicular easy axis [2,3] with diameter $D$ varied from 103 nm to 35 nm.

A stack structure, from substrate side, Ta (5)/Pt (5)/[Co (0.34)/Pt (0.4)]$_6$/Co (0.34)/Ru (0.44)/[Co (0.34)/ Pt (0.4)]$_2$/Co (0.34)/Ta (0.3)/CoFeB (1)/MgO/CoFeB (1.6)/Ta (0.3)/CoFeB (1)/MgO/capping layer, is deposited on a 3inchϕ sapphire substrate by dc/rf magnetron sputtering. The numbers in parentheses are the nominal thicknesses in nm. The stack is processed into circular MTJs with $D$ varied from 103 nm to 35 nm on striplines in a coplanar waveguide. The MTJs are annealed at 300°C for 1 hour under out-of-plane magnetic field of 0.4 T. Resistance-area product of the MTJs is ~7 Ωμm$^2$, and tunnel magnetoresistance ratio at bias voltage of ~ 10 mV is about ~90% almost independent of $D$.

After application of initializing pulse, we apply the writing voltage pulse to the MTJs with a pulse width $\tau_P$ = 50 ns, followed by application of the reading voltage pulse. The transmitted current during the application of the reading voltage pulse is measured by an oscilloscope, from which we evaluate a magnetization state, parallel (P) or anti-parallel (AP). The same measurement is repeated 16000 times at various amplitudes of the writing voltage pulse for P-to-AP reversal. WER is determined by the number of non-switching events divided by the total number of attempts. We evaluate the dependence of WER on writing pulse current $I_W$, which is determined by the transmitted current during the application of the writing voltage pulse. The writing pulse current dependence of the WER for the MTJs with $D$ = 35 and 103 nm is shown in Fig. 1. In the MTJ with $D$ = 35 nm, WER starts to reduce at a certain $I_W$ and monotonically reduces with increase of $I_W$, which is consistent with the expectation from macrospin model. On the other hand, in the MTJ with $D$ = 103 nm, the WER also starts to reduce at a certain $I_W$, but does not decrease in a monotonic manner. Transmitted current waveform for $D$ = 103 nm during switching indicates that the write error anomaly is associated with switching into an intermediate state.

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[1] T. Devolder *et al.*, Phys. Rev. B **93**, 024420 (2016). [2] S. Ikeda *et al.*, Nat. Mater. **9**, 721 (2010). [3] H. Sato *et al.*, Appl. Phys. Lett. **101**, 022414 (2012).

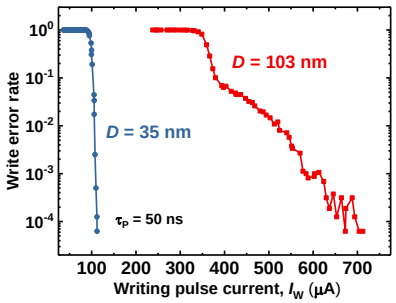


Figure 1 WER of MTJ with $D$ = 103 nm and 35 nm as a function of $I_W$ for P-to-AP switching.