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## Spintronics Device for Stand-by Power Free Nonvolatile CMOS VLSI[1]

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Recent progress in perpendicular magnetic-easy axis magnetic tunnel junctions (MTJs), a spintronics device, offers a high potential building block for constructing not only stand-alone fast and nonvolatile RAMs in the 30 nm feature size and beyond but also nonvolatile CMOS VLSI employing logic-in-memory architecture [1]. The shift from in-plane to perpendicular is prompted by the need for a high crystalline anisotropy that is available in perpendicular materials for reducing the device size. In addition, current-induced switching is inherently more efficient with perpendicular easy axis. However, satisfying both high tunnel magnetoresistance (TMR) ratio over 100% and low switching current was a challenge, because of the mismatch between MgO (100) - CoFe(B) bcc (100) structure needed to obtain high TMR and the crystal structure of perpendicular materials. It was shown that a strong perpendicular interface anisotropy exists at the MgO-CoFeB interface [2, 3], strong enough ($K_i = 1.3$ mJ/m$^2$) to overcome demagnetization energy and make the easy axis perpendicular when the ferromagnetic electrode thickness is thin enough. First principle calculation by Nakamura *et al.* showed that the perpendicular anisotropy is due to the oxygen-iron bond that reduces contribution of in-plane crystalline anisotropy [4]. By the use of this perpendicular easy axis, a 40 nm$\phi$ MgO-CoFeB MTJ with high TMR (>100 %) and low switching current of 49 $\mu$A was realized [2]. It was also pointed out that activation volume for reversal plays an important role in determining the thermal stability of the MTJs [5]. I will discuss how the MTJs are incorporated in CMOS VLSIs to make them nonvolatile and stand-by power free.

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