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Challenges of STT-MRAM for High Density Memory

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Conventional charge based memories have some problems to scale down to sub-20nm. The main reason is the decrease of the net amount of stored charges and of charge loss tolerance with scaling down. In order to overcome these issues, high-k materials as well as capacitor surface area increase are required but such process complexity can gradually weaken cost competitiveness of DRAM.

STT-MRAM (Spin-Transfer Torque MRAM) has been intensively developed as non-volatile memory because of its fast read/write speed, unlimited endurance, low power consumption and high density feasibility. However, it is not commercialized yet because of fundamentally challenging issues such as read/write operation margin, data retention, barrier reliability, and patterning process. Also, STT-MRAM with MTJ (Magnetic Tunnel Junction) consisting of easily controllable magnetic material and/or simple stacking structure may be required to realize mass production. In this point of view, i-PMA (interface-driven Perpendicular Magnetic Anisotropy) based perpendicular MTJ is attractive due to its simple structure as well as magnetic material maturity [1]. In perpendicular MTJ, however, one of issues is a strong magnetostatic interaction between magnetic layers. This coupling makes the lack of stability of each functional layer and unbalanced retention at the two data states. This becomes much more challenging issue as MTJ scales down. In this paper, the scalability of i-PMA based STT-MRAM will be discussed. We also demonstrate advanced perpendicular MTJs with a solid STT switching probability by controlling magnetostatic coupling.

Another serious issue for downscaling is the weakened data retention of MTJs. Since data retention is proportional to i-PMA strength and activation volume of free layer (FL), higher i-PMA and thicker FL should be required to obtain stable operation at sub-20nm. The origin of i-PMA has been reported by the spin-orbit coupling due to the interaction between the orbitals of oxygen in MgO tunnel barrier and transition metal in FL. Thus, FL with dual MgO interfaces has higher i-PMA compared to a single MgO interface [2]. Fig. 1 shows film-level $K_u \cdot t$ values vs. FL thickness for the two MTJs. Although the maximum $K_u \cdot t$ values for the two structures are comparable, the critical thickness of FL where anisotropy switches from perpendicular to in-plane is significantly large in dual-interface structure with higher K_s value, indicating the enhanced i-PMA due to additional interface. Thermal stability factor (Δ) of dual-interface structure can be enhanced by increasing FL thickness showing maximum i-PMA. Fig. 2 shows field switching probability of the two different MTJs patterned down to 20nm. The MTJ of dual interfaces shows sharper distribution, yielding Δ higher than 60. This means that i-PMA based STT-MRAM consisting of relatively simple and matured material has the scalability down to sub-20nm.

Since MTJ consists of two or more magnetic layer separated by very thin tunnel barrier of ~ 1nm thickness, there exists strong magnetic coupling between magnetic layers and its strength increases with scaling down. In addition the increase of off-set field (H_{offset}) with scaling generally results in bad switching probability. Fig. 3 shows the dependence of coercivity (H_c) and H_{offset} on various scaling node in pMTJ with i-PMA based FL and synthetic antiferromagnetically (SyAF)-coupled [Co/Pd] multilayer. H_{offset} is larger than H_c below 25nm, which causes the decrease of STT switching probability. This switching probability also depends on the overlap window of switching fields of FL and PL as well as H_{offset}. In order to obtain a robust switching window, we demonstrate novel MTJ which can overcome the overlap issue of switching fields of FL and PL with maintaining the improved H_{offset} controllability [3]. Switching field of PL in novel structure is above 9kOe, which leads much larger switching field margin than 12σ. Moreover, the well-controlled H_{offset} characteristic induces the wild STT switching margin, even though sub-10nm MTJ.

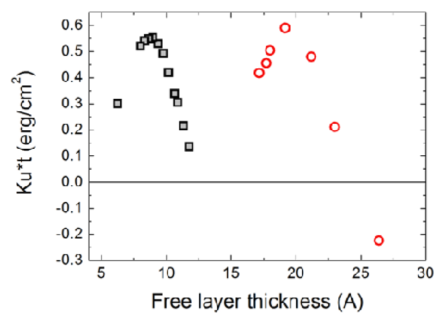

Fig. 1 Plot of $K_u \cdot t$ vs. free layer thickness for single-interface (gray square) and dual-interface (red circle) MTJs

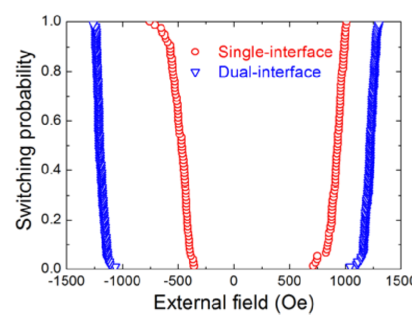

Fig. 2 Switching probability vs. external field for the two different types of MTJ cells (of one bit) patterned at 20 nm nodes. Δ for single and dual interface is about 66 and 33, respectively.

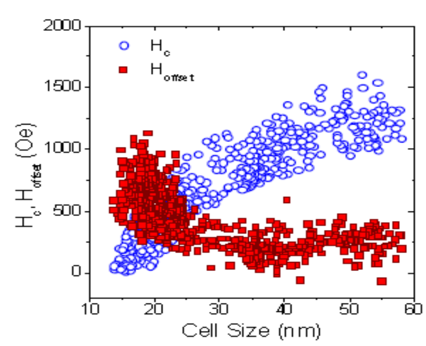

Fig. 3 Coercivity and offset field distribution of i-PMA based MTJs as a function of MTJ cell size.

[1] Woojin Kim *et al.*, IEEE International Electron Devices Meeting, pp. 24.1.1-24.1.4 (2011).
[2] J. H. Park *et al.*, IEEE Symposium on VLSI Technology, pp. 57-58 (2012).
[3] W. C. Lim *et al.*, accepted in IEEE Symposium on VLSI Technology (2013)