Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp402-403

PS-12-6

High Thermal Stability and Low Switching Energy Barrier in Spin-transfer Torque RAM with Composite Free Layer

Alexander Makarov, Viktor Sverdlov, and Siegfried Selberherr

Institute for Microelectronics, TU Wien
Gußhausstraße 27-29, A-1040 Wien, Austria
Phone: +43(1)58801-36028 E-mail: Makarov@iue.tuwien.ac.at

1. Introduction

Magnetoresistive random access memory with spin-transfer torque (STT-MRAM) is a promising candidate for future universal memory [1]. Perpendicular MTJs (p-MTJ) with interface-induced anisotropy demonstrate reduction of switching energy, but still require damping reduction and thermal stability increase [2]. Therefore, research of new materials and architectures for MTJ structures is intensifying. A penta-layer MTJ with a composite free layer (Fig.1) proposed in [3] has demonstrated a substantial decrease of the switching time (Fig.2) and current reduction as compared to an MTJ with a monolithic free layer. The composite magnetic layer consists of two half-ellipses separated by a non-magnetic spacer. In contrast to p-MTJs [2], the magnetization of the magnetic layers lies in-plane. This allows to broaden substantially the scope of the magnetic materials suited for constructing MTJs. Here we discuss scalability and reduction of switching energy, and we outline a method for increasing the thermal stability of MTJs with a composite free layer.

2. Modeling and Results

All simulations are performed for the nanopillar CoFeB(5nm)/MgO(1nm)/CoFeB/MgO(1nm)/CoFeB(5nm) MTJ, for a broad range of elliptical cross-sections from 27.5×10 to 155×60nm^2. Other parameters are: T=300K, M_s=M_{sp}=8.9·10^{5}A/m, A=1·10^{-11}J/m, K=2·10^3 J/m^3 and η=0.63 [4]. The simulations are based on the magnetization dynamics described by the Landau-Lifschitz-Gilbert-Slonczewski (LLGS) equation with additional spin torque terms [3]:

$$\frac{dm}{dt} = -\frac{\gamma}{1+\alpha^2}\cdot\left(\left(m\times h_{eff}\right)+\alpha\cdot\left[m\times\left(m\times h_{eff}\right)\right]\right.$$
$$+\frac{g\mu_B j}{e\gamma M_s d}\cdot\left(g_1(\theta_1)\cdot\left(\alpha\cdot(m\times p_1)-\left[m\times(m\times p_1)\right]\right)\right. \quad (1)$$
$$\left.\left.-\,g_2(\theta_2)\cdot\left(\alpha\cdot(m\times p_2)-\left[m\times(m\times p_2)\right]\right)\right)\right).$$

Here, γ=2.3245·10^{5}m/(A·s) is the gyromagnetic ratio, α=0.005 is the Gilbert damping parameter, g is the gyromagnetic splitting factor, μ_B is Bohr's magneton, j is the current density, e is the electron charge, d is the thickness of the free layer, $m=M/M_s$ is the position dependent normalized vector of the magnetization in the free layer, $p_1=M_{p1}/M_{sp1}$ and $p_2=M_{p2}/M_{sp2}$ are the normalized magnetizations in the first and second pinned layers, respectively.

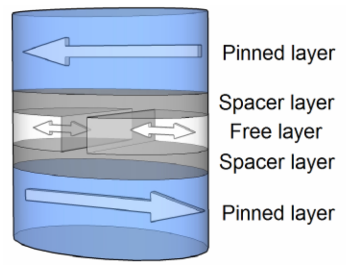

Fig. 1. Schematic illustration of a penta-layer MTJ with a composite free layer.

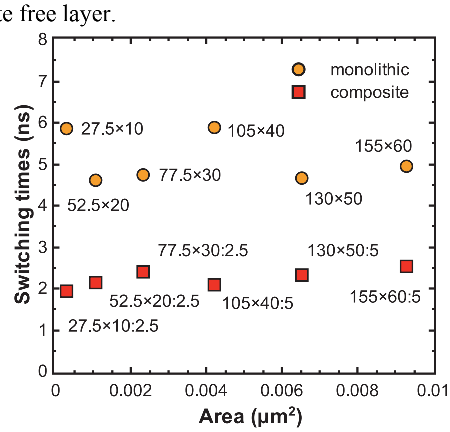

Fig. 2. Average value of the switching times for MTJs with monolithic and composite free layer as function of the cross-section area. Each point is a result of statistical averaging with respect to 50 different realizations of the switching process.

M_s, M_{sp1}, and M_{sp2} are the saturation magnetizations of the free layer, the first pinned layer, and the second pinned layer, correspondingly. We use Slonczewski's expressions for the MTJ with a dielectrical layer [5]:

$$g_1(\theta) = 0.5\cdot\eta\cdot\left[1+\eta^2\cdot\cos(\theta)\right]^{-1}. \quad (2)$$

First we investigated the influence of scaling on the thermal stability factor [6] for MTJs with composite and monolithic free layers. Due to the removal of the central region in the monolithic structure the shape anisotropy (Fig.3) is decreased together with the thermal stability factor. To increase the thermal stability factor it is sufficient to increase the thickness of the free layer and/or the aspect ratio. Fig.4 shows the thermal stability factors for MTJs with a composite free layer as function of the short axis. An MTJ with 52.5×10nm^2 cross section and 5nm thickness of the free layer has a thermal stability factor ~60kT, which exceeds that for the p-MTJ demonstrated so far [7].

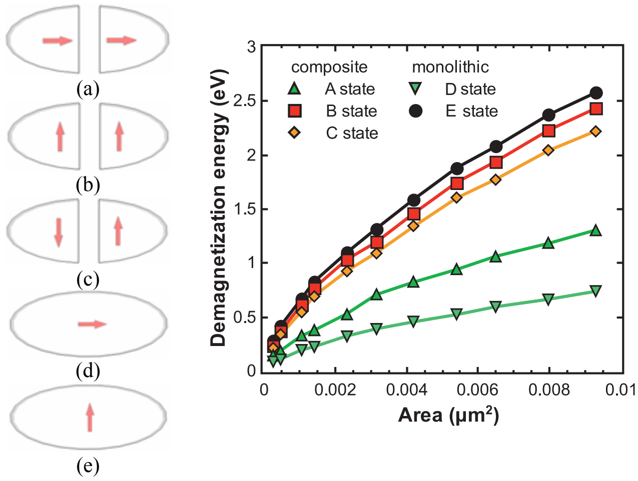

Fig. 3. Dependence of the demagnetisation energy for MTJs with composite (a,b,c) and monolithic (d,e) free layers as function of the cross-section area.

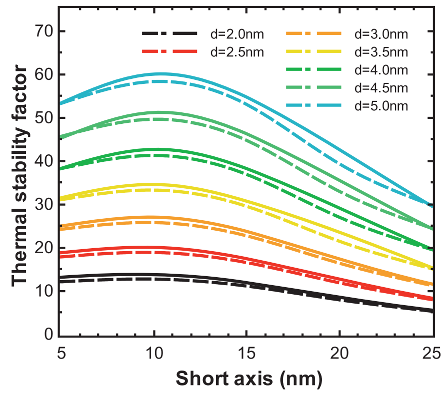

Fig. 4. Thermal stability factor for MTJs with a composite free layer as function of the short axis. The long axis is fixed at 52.5nm. Dependences are shown for simulations with discretization cells: $2.5\times2.5\text{nm}^2$ (dash lines) and $1.25\times1.25\text{nm}^2$ (full lines).

In the following we compare the height of the thermal energy barrier with that of the switching energy barrier. Fig.5 shows that, as in p-MTJs, the switching barrier in an MTJ with composite free layer becomes practically equal to the thermal stability barrier determined here by the shape anisotropy. This is in agreement with earlier results [8], where, based on the analysis of the magnetization dynamics, it was shown that the switching processes of the left and right parts of the composite free layer occurs in opposite senses to each other (Fig.3c).

Fig. 6 shows the ratio of the switching energy barrier in monolithic and composite structures. It displays an almost 14-fold decrease of the switching energy in MTJs with composite layer.

3. Conclusions

Magnetic tunnel junctions with a composite free layer are studied by means of extensive micromagnetic calculations. As in p-MTJs, in such structures the switching energy is practically equal to the thermal stability barrier. However, the thermal stability factor exceeds that for p-MTJs demonstrated so far. The investigated structure offers great potential for performance and thermal stability optimization of STT-MRAM devices.

Acknowledgements

This research is supported by the European Research Council through the grant #247056 MOSILSPIN.

References

[1] R. Sbiaa *et al.*, Phys. Stat. Solidi RRL **12** (2011) 413.
[2] H. Ohno, SSDM (2011) 957.
[3] A. Makarov *et al.*, Phys. Stat. Solidi RRL **12** (2011) 420.
[4] M. Iwayama *et al.*, J. Appl. Phys. **103** (2008) 07A720.
[5] J. Slonczewski, Phys. Rev. B, **71** (2005), 024411.
[6] P. Khalili Amiri, IEEE Electron Dev.Lett. **32** (2011) 57.
[7] H. Sato *et al.*, Appl. Phys. Lett., **99** (2011), 042501.
[8] A. Makarov *et al.*, SISPAD 2012, submitted.

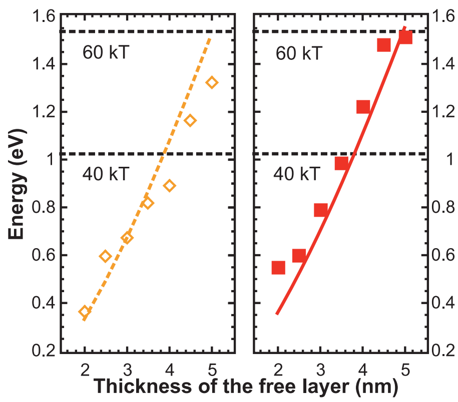

Fig. 5. Thermal energy (lines) versus switching energy (symbols) barriers for MTJs with composite free layer and $52.5\times10\text{nm}^2$ cross-section as function of thickness of the free layer. Each point is a result of statistical averaging with respect to 30 different realizations of the switching process. Dependences are shown for simulations with discretization cells: $2.5\times2.5\text{nm}^2$ (left) and $1.25\times1.25\text{nm}^2$ (right).

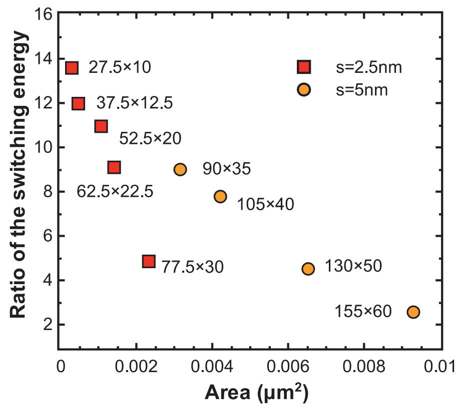

Fig. 6. Ratio of the switching energy barriers in the monolithic to the composite structure as function of the cross-section area. Each point is a result of statistical averaging with respect to 50 realizations of the switching process.