Micromagnetic Simulations of an MTJ with a Composite Free Layer for High-Speed Spin Transfer Torque RAM

A. Makarov, V. Sverdlov, and S. Selberherr
Institute for Microelectronics, TU Wien, Gußhausstraße 27-29, 1040 Wien, Austria
e-mail: {makarov | sverdlov | selberherr}@iue.tuwien.ac.at

INTRODUCTION

Spin Transfer Torque RAM (STTRAM) is a promising candidate for future memory applications [1]. The reduction of the current density required for switching and the increase of the switching speed are the most important challenges in STTRAM development. Recently a substantial decrease of the switching time in a penta layer structure with a composite free layer (Fig.1) was reported [2]. Here we reveal the physical reasons for the switching time reduction at the same current density, discuss scalability, and outline a method for increasing the thermal stability of MTJs with a composite free layer.

SIMULATIONS AND RESULTS

We investigated the structure CoFeB (5nm)/ spacer (1nm)/CoFeB (2nm)/spacer (1nm)/CoFeB (5nm) with elliptical cross-section from 27.5×10 to 155×60nm^2. The system with a composite ferromagnetic layer is obtained by removing a central stripe from the monolithic free layer. The simulations are based on the magnetization dynamics described by the LLG equation with additional spin torque terms [2], [3].

Fig.2 shows a decrease of the switching time in MTJs with a composite free layer as compared to that with a monolithic free layer of similar dimensions for all cross-section areas. When the central region is removed, the end domains become virtually independent and switch without forming domain walls (Fig.3). The switching process in a monolithic structure with a gradual decrease of the exchange coefficient A_c between the central elements is shown in Fig.4. The switching time in a penta layer structure is decreasing with decreasing exchange and becomes equal to the switching time in a structure with composite free layer, when A_c=0.

Next we compare the thermal stability factor [4] for MTJs with composite and monolithic free layers. Due to the removal of the central region in the monolithic structure the shape anisotropy is decreased together with the thermal stability factor (Fig.5). To increase the thermal stability factor it is sufficient to increase the thickness of the free layer and/or the aspect ratio. Our simulation results (Fig.6) indicate that MTJs with a composite layer with 52.5×10nm^2 cross section and 4nm thickness of the free layer have a good retention with a thermal stability factor 45.

CONCLUSION

We thus demonstrated the possibility of creating a STTRAM with fast switching and improved stability on the basis of MTJs with composite layers.

ACKNOWLEDGEMENT

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REFERENCES

[1] H. Ohno, *Magnetoresistive Random Access Memory with Spin Transfer Torque Write (Spin RAM) – Present and Future*, SSDM, 957 (2011).
[2] A. Makarov et al., *Reduction of Switching Time in Penta-layer Magnetic Tunnel Junctions with a Composite-Free Layer*, Phys.Stat.Solidi RRL **5**, 420 (2011).
[3] M. Iwayama et al., *Reduction of Switching Current Distribution in Spin Transfer Magnetic Random Access Memories*, J.Appl.Phys. **103**, 07A720 (2008).
[4] P. Khalili Amiri, *Low Write-Energy Magnetic Tunnel Junctions for High-Speed Spin-Transfer-Torque MRAM*, IEEE Electron Dev.Lett. **32**, 57 (2011).

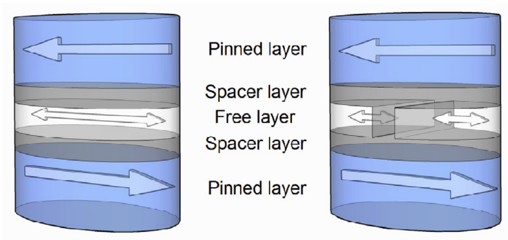

Fig. 1. Schematic illustration of penta-layer MTJs with monolithic (left) and composite free layer (right).

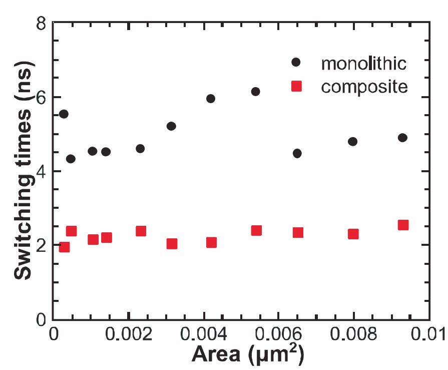

Fig. 2. Absolute values of the switching times for MTJs with monolithic and composite free layer as function of the cross section area.

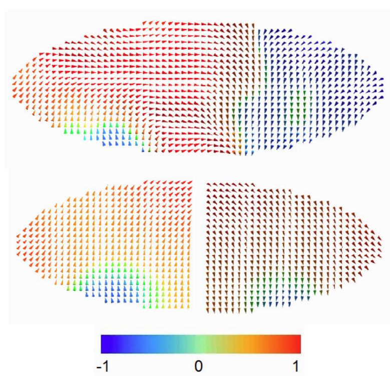

Fig. 3. Snapshots of the switching process for an MTJ with (top) monolithic and (bottom) composite free layer (145×55nm^2).

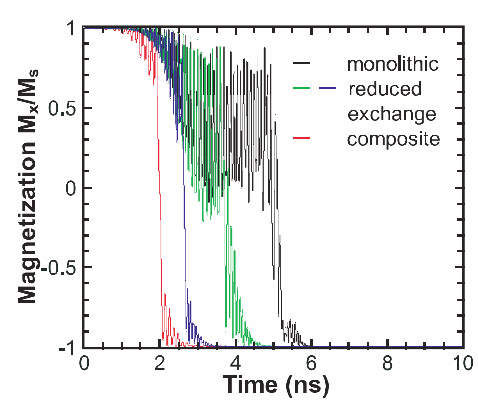

Fig. 4. The switching process for an MTJ with cross-section 90×35nm^2 with different exchange between the end elements.

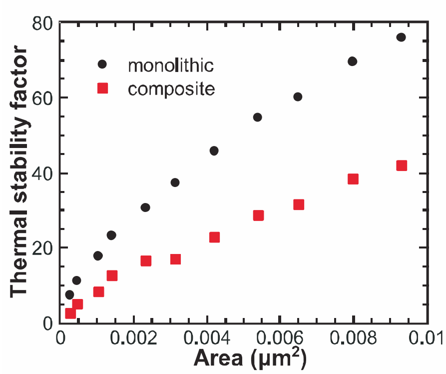

Fig. 5. Thermal stability factor for MTJs with monolithic and composite free layer as function of the cross section area.

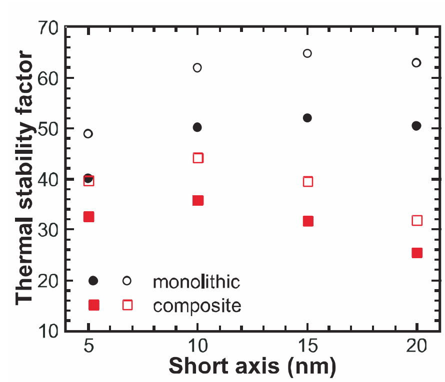

Fig. 6. Thermal stability factor for MTJs with monolithic and composite free layer as function of the short axis. The long axis is fixed at 52.5nm. The thickness of the free layer 3.5nm (filled symbols) and 4nm (open symbols).