Structural Optimization of MTJs with a Composite Free Layer

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INTRODUCTION

New types of spintronics devices utilizing magnetization switching by current, such as spin-torque transfer RAM and spin-torque oscillators, have been intensely developed based on MgO magnetic tunnel junctions (MTJs) with a large magneto-resistance ratio [1], [2] (Fig.1a). At the same time the research on new materials and architectures for MTJ structures has recently gained momentum. A MTJ with a composite free layer (C-MTJ) was proposed [3-5]. The free magnetic layer of such a structure consists of two equivalent parts of half-elliptic form separated by a narrow non-magnetic spacer (Fig.1b). The C-MTJs demonstrate a substantial decrease of the switching time and switching current as compared to the standard MTJ with the monolithic free layer.

In this work we present a structural optimization of C-MTJs (Fig.1b) by means of extensive micromagnetic simulations and propose a new structure of the composite free layer, C2-MTJ (Fig.1c).

SIMULATIONS AND RESULTS

In C2-MTJs the free layer consists of two ellipses with the major axes *a/2* and *b* (*a>2b*) inscribed into a rectangle $a \times b$. This structure is easier to fabricate as compared to the previous generation of C-MTJs (Fig.1b). The simulations are based on the magnetization dynamics described by the LLG equation with the additional spin torque terms [3-5].

We found that both C-MTJ and C2-MTJ composite structures have the same switching time (Fig.2), i.e. the fast switching in C2-MTJ is preserved (Fig.3b) as compared to the monolithic M1-MTJ. Despite the modification in shape, the C2-MTJ is characterized by the same thermal stability as C-MTJ (Fig.4). Note, that the C2-MTJ exhibits the same switching time as the monolithic structure (M2-MTJ) with one small ellipse (Fig.3a), while possessing nearly a two times larger thermal stability factor (Fig.5). The dependence of the width of the standard deviation on the composite layer thickness is shown in Fig.6 for several values of the short axis. A C2-MTJ with $52.5\times25\text{nm}^2$ cross section, as well as C-MTJs [4], has the width of the standard deviation of switching times $\sim10^{-3}$ns, while for a MTJ with $52.5\times10\text{nm}^2$ cross section the value is considerably larger (0.3-1ns).

Next, we look at the magnetization dynamics of the left and right part of the C2-MTJ free layer separately (Fig.7). We found that the peculiarity of the switching behavior of C-MTJs [4], where the switching occurs mostly in the *x-y* plane, is preserved in C2-MTJs (Fig.7). Thus, the switching barrier in a C2-MTJ is practically equal to the thermal stability barrier defined by the shape anisotropy, as confirmed in Fig.8.

CONCLUSION

We proposed the new C2-MTJ structure with a composite free layer. Our simulations show that, while preserving all the advantages of the C-MTJs, the newly proposed structure can be easier fabricated, offering great potential for STT-MRAM performance optimization.

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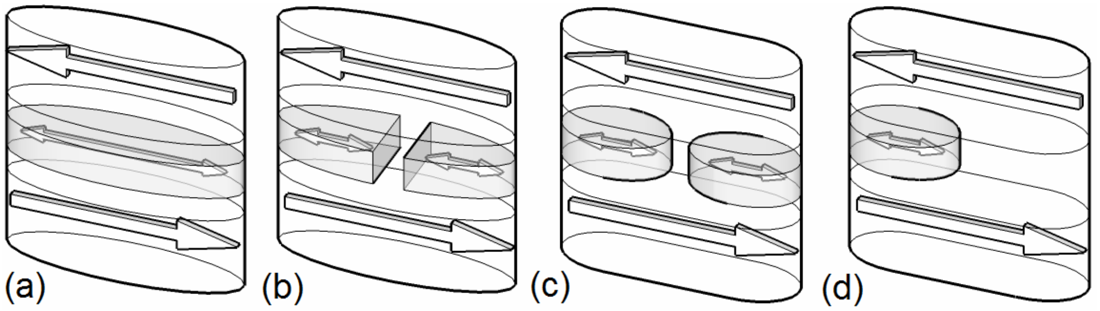

Fig. 1. Schematic illustration of penta-layer MTJs with monolithic free layer M1-MTJ (a) and M2-MTJ (d), and composite free layer C-MTJ (b) and C2-MTJ (c).

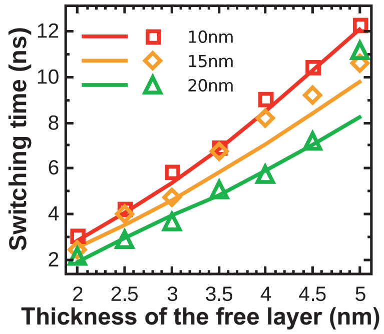

Fig. 2. Switching time of the C-MTJ (symbols) and C2-MTJ (lines) as function of the thickness of the free layer. The long axis is fixed at 52.5nm and the thickness of the fixed layers are 5nm. Dependences are shown for short axes of 10nm, 15nm, and 20nm length.

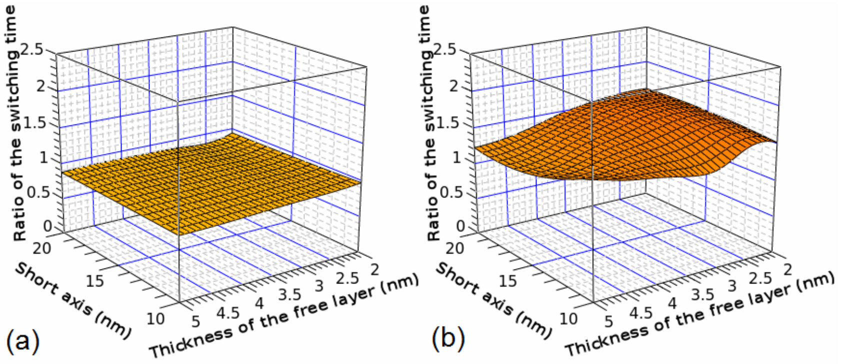

Fig. 3. Ratio of the switching times in the monolithic structure and composite structure as function of thickness of the free layer and short axis length. The long axis is fixed at 52.5nm. Dependences are shown for ratio: M2-MTJ vs. C2-MTJ (a), M1-MTJ vs. C2-MTJ (b).

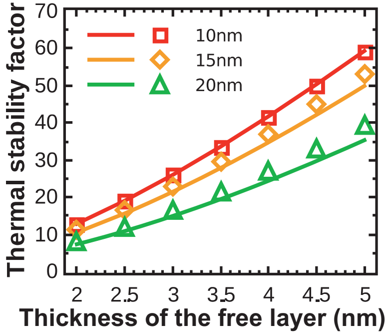

Fig. 4. Thermal stability factor for C-MTJ (symbols) and C2-MTJ (lines) as function of the thickness of the free layer. The long axis is fixed at 52.5nm and the thickness of the fixed layers are 5nm. Dependences are shown for short axes of 10nm, 15nm, and 20nm length.

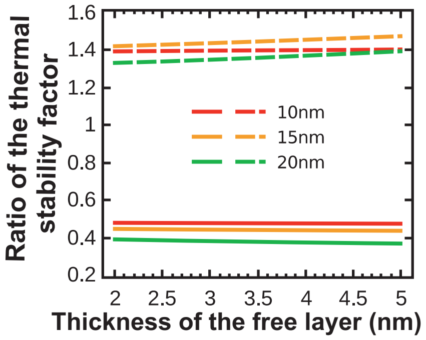

Fig. 5. Ratio of the thermal stability factor for monolithic structure and composite structure as function of thickness of the free layer and short axis length. The long axis is fixed at 52.5nm. Dependences are shown for ratio: M2-MTJ vs. C2-MTJ (solid lines), M1-MTJ vs. C2-MTJ (dotted lines).

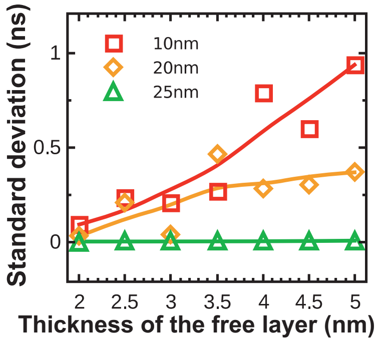

Fig. 6. The standard deviation of the switching time distribution in the composite structure as a function of thickness of the free layer. The long axis is fixed at 52.5nm and the thickness of the fixed layers are 15nm. Dependences are shown for short axes of 10nm, 20nm, and 25nm length.

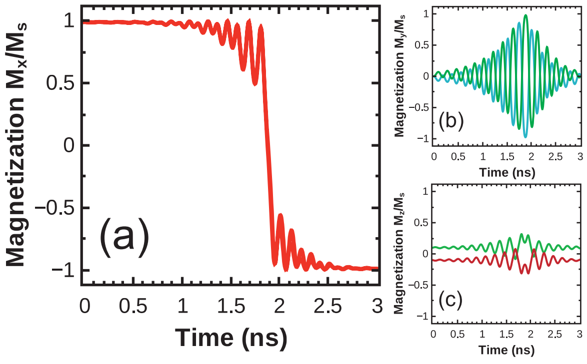

Fig. 7. Magnetization components as a function of time for a MTJ element of 52.5×20nm^2 with a composite free layer (C2-MTJ). The magnetization of the left and right half is shown separately.

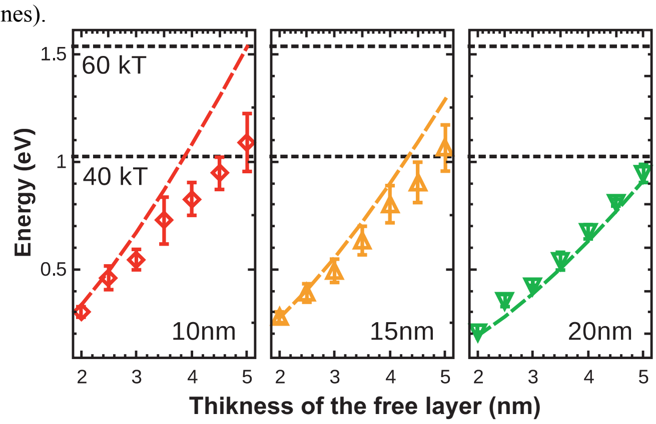

Fig. 8. Thermal energy (lines) vs. switching energy (symbols) barriers for C2-MTJ. The long axis is fixed at 52.5nm and the thickness of the fixed layers are 5nm. Dependences are shown for short axes of 10nm, 15nm, and 20nm length.