Student Paper

Switching time and current reduction using a composite free layer in magnetic tunnel junctions

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The theoretical predictions [1] and the experiments [2] of spin transfer switching demonstrated that the spin transfer torque random access memory (STTRAM) is one of the promising candidates for future universal memory. The basic element of the STTRAM is a magnetic tunnel junction (MTJ), a sandwich of two magnetic layers separated by a thin non-magnetic spacer (Fig.1a). The reduction of the current density required for switching and the increase of the switching speed are the most important challenges in STTRAM research [3]. It has been demonstrated [4] that the critical current density is decreased in a penta-layer magnetic tunnel junction as shown in Fig.1b.

We performed extensive micromagnetic modeling of penta-layer structures composed of CoFe / spacer(1nm) / Py (4nm) / spacer (1nm) / CoFe (Py is $Ni_{81}Fe_{19}$) with a composite free layer (Fig.1c) by employing the Slonczewski model [1], [5] for the spin torque.

Figure 1 shows a substantial decrease of the switching time in the penta-layer structure with the composite free layer, for the same current density j=10MA/cm^2. The non-zero angle between the fixed magnetization and the magnetization in the free layer result in enhanced spin transfer torque, when the current starts flowing. In the case of the monolithic structure, however, the torque remains marginal in the central region. As the amplitude of the end domains precession increases, the central region experiences almost no spin torque and preserves its initial orientation along the x axis. This is not the case, when the central region is removed. Snapshots of the magnetization highlighting the differences in switching are shown in Fig. 2. Fig.3 demonstrates the decrease of the switching time in a penta-layer structure with a composite free layer as the thickness of the pinned layers is increased. This is due to the fact that the z-component of the magnetostatic field h_{ms} (Fig.4) increases together with the pinned layer thickness causing a larger initial angle (Fig.4, Inset), larger torque, and, as a consequence, a shorter switching time. Larger torque allows to use lower current density for switching (Fig. 6).

Due to the removal of the central region, which represented the “bottleneck” for switching in the monolithic structure, the shape anisotropy energy slightly decreases. However, its value is still sufficiently large for guaranteeing the thermal stability at operation conditions [4].

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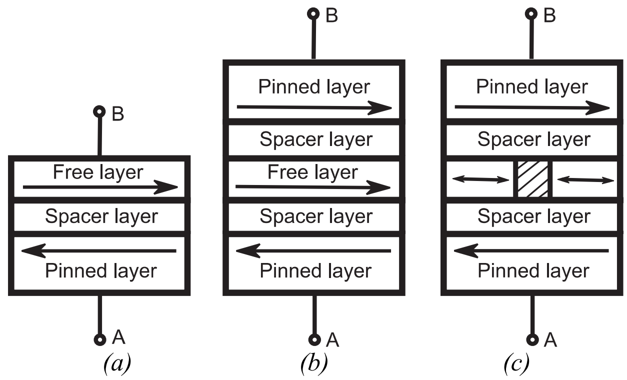

Fig. 1 Schematic illustration of the:
(a) three-layer MTJ; (b) penta-layer MTJ with monolithic free layer; (c) penta-layer MTJ with composite free layer.

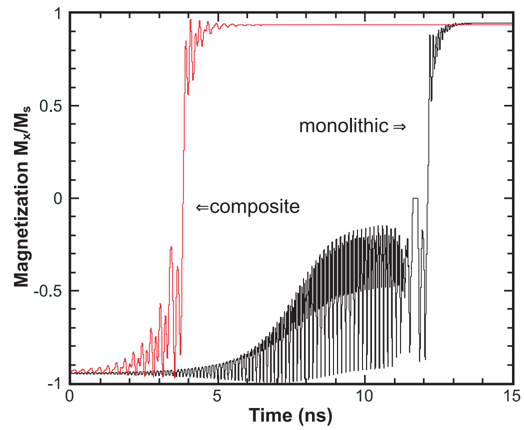

Fig. 2 The switching process for an MTJ with composite and monolithic free layer for a pinned layer thickness of 15nm.

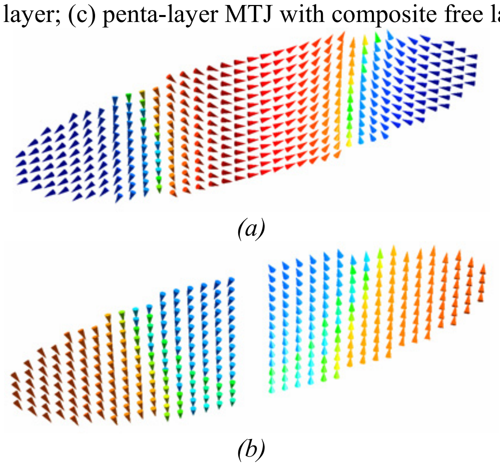

Fig. 3 Snapshots of the magnetization:
(a) monolithic free layer; (b) composite free layer.

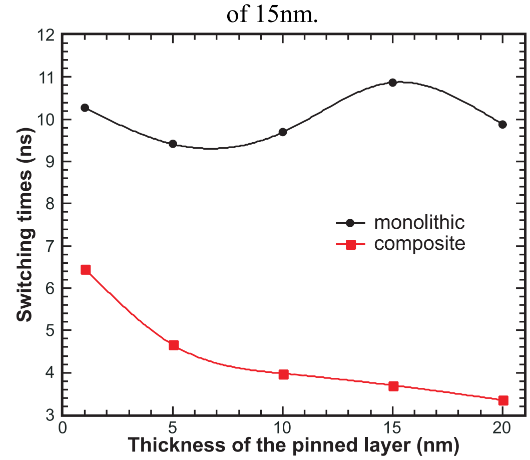

Fig. 4 The absolute values of the switching times for MTJs with monolithic and composite free layer as the function of the pinned layer thickness.

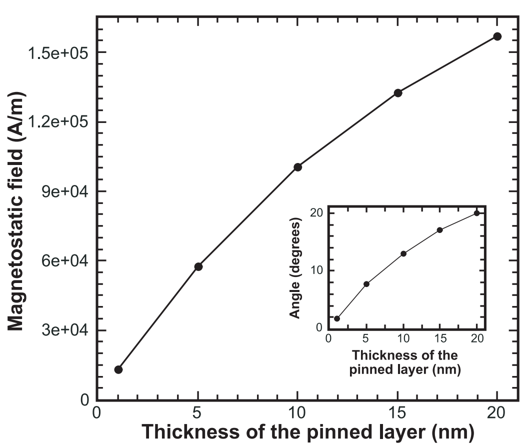

Fig. 5 The dependence of the absolute values of the z-component of the averaged magnetostatic field as the function of the pinned layer thickness. The inset shows the averaged initial angle.

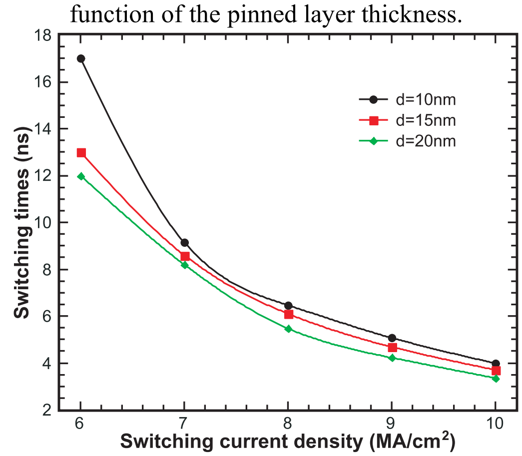

Fig. 6 The dependence of the switching times as the function of the current density for the pinned layer thicknesses of 10nm, 15nm, and 20nm.