Comprehensive Modeling of Switching in Perpendicular STT-MRAM

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Introduction of non-volatility in modern integrated circuits dramatically reduces the stand-by power and leakages. Spin-transfer torque (STT) magnetoresistive random access memory (MRAM) combines high speed, excellent endurance, and low costs and is promising for applications ranging from IoT and automotive applications to embedded DRAM and L3 caches [1]. In MRAM the binary information is stored as the parallel/anti-parallel configuration of the magnetic layers in a magnetic tunnel junction (MTJ). The switching between the two configurations is achieved by passing current through the MTJ. In simulating STT switching, for simplicity it is usually assumed that the current density J(**r**,t) is position- and time-independent [2]. Practically, however, it is the voltage which remains constant at switching rather than the current density. As the relative magnetization alignment is locally modified at the switching, so is the local tunneling resistance. Thus, different current densities are flowing through different parts of the MTJ with different magnetization alignments (Fig.1). Therefore, the assumption of a constant current density is questionable, especially in MTJs with a tunneling magnetoresistance ratio (TMR) larger than 200% [3].

In order to validate the assumption of the constant current density for evaluating the switching time, we first consider the model in which the total current is fixed, but the current density is determined by the local magnetization alignment and the corresponding local TMR. The switching times depend on the realization of the stochastic magnetic field mimicking the magnetization fluctuations at room temperature. It turns out that the average switching times within the models with the fixed current and the fixed current density are very similar for both parallel (P) to anti-parallel (AP) and AP to P switching of a perpendicular MTJ (Fig.2). However, the switching for the fixed, constant voltage, with a value chosen so that the initial current and the torque are the same, looks quite different (Fig.2) [4]. The difference is due to the fact that in the model with fixed voltage the current depends on the varying resistance of the MTJ. In order to compensate the effect of the varying resistance, the current value in the models with the fixed current must be increased by ~10% for AP to P and decreased by ~5% for P to AP switching, for TMR=200%. Fig.3 demonstrates that after these corrections the switching times as a function of the stray field within the fixed voltage and fixed current models are very similar.

The dependence of the current correction in relation to the value providing the same initial torque is shown in Fig.4 as a function of the TMR. The results imply that the use of the constant current density model is justified also in the realistic case of switching at a constant voltage, provided that the current is appropriately corrected for the P to AP and the AP to P scenario.

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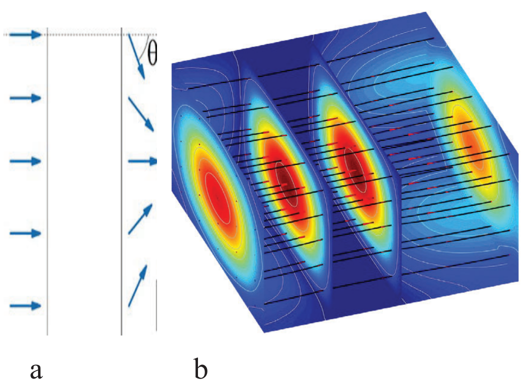

Fig.1: (a) Position dependent magnetization alignment in an MTJ and (b) the current density distribution under a fixed voltage V.

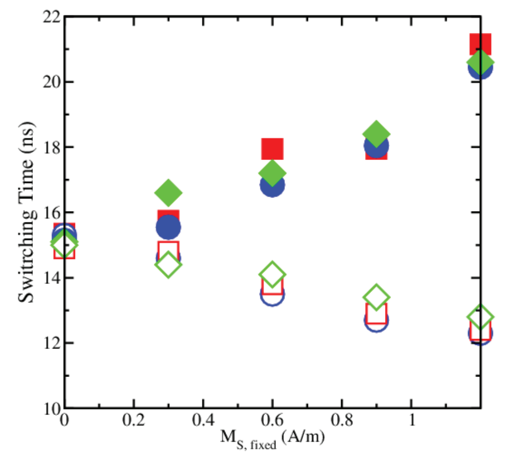

Fig.3: All three models give consistent results, if the current I is corrected from its initial value I=V/R as described in the text.

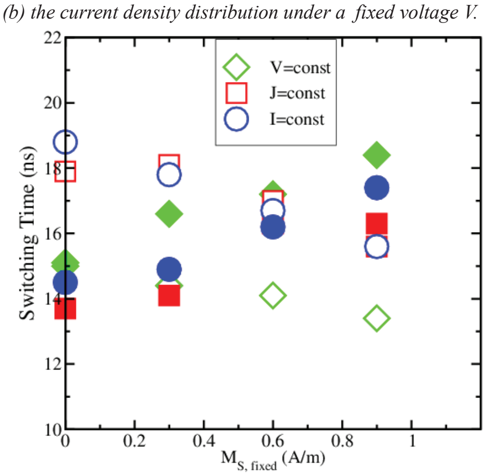

Fig.2: Switching times for three models with a fixed voltage V, fixed current I=V/R (R is the resistance before switching), and fixed current density J. The size of the open (P->AP) and filled (AP->P) symbols corresponds to the width of the switching time distribution.

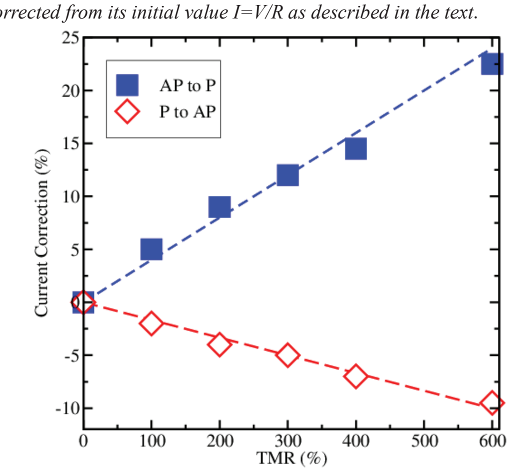

Fig.4: The correction to the current I as a function of TMR, which must be given in order for all three models to give consistent results, for both parallel to anti-parallel and anti-parallel to parallel switching. The dashed lines represent a linear fit.