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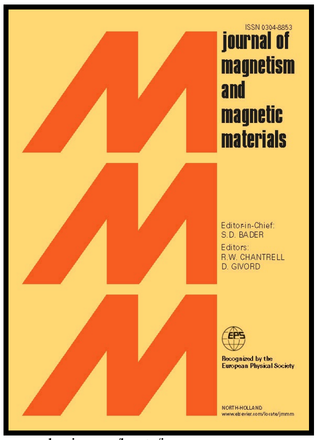

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State diagram of a perpendicular magnetic tunnel junction driven by spin transfer torque: a power dissipation approach

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The state diagram of a magnetic tunnel junction with perpendicularly magnetized electrodes in the presence of spin-transfer torques is computed in a macrospin approximation using a power dissipation model. Starting from the macrospin's energy we determine the stability of energy extremum in terms of power received and dissipated, allowing the consideration of non-conservative torques associated with spin transfer and damping. The results are shown to be in agreement with those obtained by direct integration of the Landau-Lifshitz-Gilbert-Slonczewski equation. However, the power dissipation model approach is faster and shows the reason certain magnetic states are stable, such as states that are energy maxima but are stabilized by spin transfer torque. Breaking the axial system, such as by a tilted applied field or tilted anisotropy, is shown to dramatically affect the state diagrams. Finally, the influence of a higher order uniaxial anisotropy that can stabilize a canted magnetization state is considered and the results are compared to experimental data.

I. INTRODUCTION

The development of magnetic memories using spin transfer torque (STT MRAM) has led to the use of perpendicular magnetic tunnel junctions (pMTJ) to improve the write current efficiency and maintain thermally stable magnetic states as the junction lateral size is reduced [1,2]. A pMTJ consists of two magnetic layers separated by a tunnel barrier. The magnetization direction of the reference layer is considered fixed, whereas the magnetization of the free layer can be changed with a magnetic field or an applied voltage through spin transfer torque (STT) [3-5]. For perpendicular devices in the macrospin approximation, the free layer magnetization has only two stable states either parallel (P) or antiparallel (AP) to the direction of the reference layer.

The tunnel magnetoresistance [6] (TMR) of the device is used to read the information, through the change in resistance of the junction when it switches from one configuration to the other. Since more than a decade, MgO-based tunnel junctions were shown to display a TMR ratio greater than 100% after annealing [7,8], making them interesting devices for industry.

To write efficiently information in a pMTJ, using either magnetic field or spin transfer torque, the P and AP states both have to be stable. The state diagram of a device is built by determining the magnetic state (AP or P) of the pMTJ as a function of the applied voltage and field. This provides a map of the region of junction bistability, in which either P or AP states are possible. This has been extensively studied for spin-valves [9-14] but less for MTJs [17].

The spin transfer torque in MTJs depends on the voltage. There are two contributions, the Slonczewski term [3,4], which can add or reduce the effect of the damping, and the field like torque, usually negligible in spin-valve junctions, that acts as an effective field. In contrast to spin valves, in MTJs the coefficient of the Slonczewski term does not depend in the angle formed by the magnetic moments of the reference layer and the free layer [18-20].

To analytically compute the stability of each state, the Landau-Lifschitz-Gilbert equation with two STT terms is used (Eq. 1). It describes the dynamics of the magnetization under an effective magnetic field and a bias voltage: