Numerical analysis of the nonlinear excitation of subcritical spin-wave modes within a micromagnetic framework

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I. Introduction

The discovery of the phenomenon of Giant Magnetoresistance (GMR) [1] and of its dual Spin-Transfer Torque (STT) [2] gave rise to an exponential growth of the research in the field of magnetic memories and oscillators. With respect to this latter case, in particular, it has been theoretically demonstrated and experimentally validated that the possibility to sustain a stable microwave oscillation in STT-driven magnetic systems is conceivable through the balance between the natural positive damping and the current-induced negative one [3]. The achievement of such condition leads the system in an out-of-equilibrium zero-dissipation stationary state which physically corresponds to the excitation of spin-wave modes. From the experimental point of view, a configuration generally used to trigger this dynamics is the so-called nanocontact geometry [3,4]. In particular, it was theoretically shown that such setup can support at least two structurally different spin-wave modes excited by a spin-polarized current: a supercritical cylindrical propagating quasi-linear Slonczewski-like mode [3] and a subcritical self-localized standing nonlinear soliton-like “bullet” mode [5]. Even though both theories match satisfactorily well most of the experimental observations [4], some difficulties have been encountered in the attempt to reproduce a spin-wave bullet mode within a simplified micromagnetic framework [6]. In fact, owing to the subcritical nature of a “bullet” mode, it presents a non-zero amplitude at the threshold of excitation which in turn demands for a finite level of initial magnetization fluctuations to manifest itself. So far, the only way to provide such nonlinearities, within a zero-temperature framework, implies the usage of a hysteretic procedure in which the current has to be swept back and forth [6]. Despite of this, the real source of the required fluctuations has been not fully identified so far. To clarify this issue, we investigate the role of both current-induced Oersted and thermal field (neglected in previous calculations) by performing a multi-domain micromagnetic analysis. In our technique, we start from the equilibrium state (solution of Brown’s equation) and then perturb the system by applying progressively increasing currents. The main goal consists on the possibility to observe the cited subcritical spatially-localized spin-wave modes, whose spectrum lies below the FMR frequency, for a current value smaller than the one corresponding to the linear threshold of excitation [3,5].

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II. Micromagnetic Study

To perform a proper comparison, the study is performed by using the same setup (and parameters) used in Ref.[6].

Results of investigations carried out in presence of the Oersted field reveal that it cannot be considered the searched source of fluctuations since no subcritical modes have been observed below the linear excitation threshold. In addition, it introduces a range of current values where quite chaotic dynamics are observed, yields a non-monotonous dependence of frequency on the applied current and destroys the hysteretic behavior observed in [6].

On the contrary, calculations performed in presence of thermal field (considered as an additive stochastic contribution to the effective field) show that a bullet mode can be observed for current values smaller than the linear threshold of excitation and thus thermal fluctuations represent the main contribution to the excitation of such a mode in laboratory experiments [4]. However, within such a non-deterministic framework (governed by Langevin dynamics), the excitation of thermally-activated subcritical modes occurs over much larger time scales. Consequently, to maintain the computational time within a reasonable range, alternative techniques (based, for example, on the application of some short high-temperature pulses) are required to speed-up the excitation process.

If different operating conditions are considered, the present study could be applied to simultaneously excite, in different time-windows selected by temperature, both supercritical [3] and subcritical [5] spin-wave modes.

References

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