Non-stationary soliton-like modes driven by spin-polarized current

Giovanni Finocchio , Giancarlo Consolo[1], Luis Torres, Bruno Azzerboni[1]

After the theoretical prediction and the experimental validation that a spin-polarized current passing through a thin magnetic layer can excite microwave magnetization oscillations, lots of efforts have been done in order to design the optimal setup and to gain a deep physical understanding of the mechanism underlying the dynamics of spin-torque oscillator[1,2]. The oscillation phenomenon in nanoscale spin-valve manifests itself by either an uniform coherent rotation of magnetization or a domain motion (in presence of non-uniform magnetization) as function of applied field and current[3]. In point-contact geometries, in particular, the spin-wave modes which can be supported are: (i) the linear propagating Slonczewski mode, mainly observed for out-of-plane bias field configuration[4] and (ii) the self-localized non-propagating bullet mode, mainly observed for in-plane field configuration[5]. For this class of devices, it has been recently investigated the nature of the excited modes as function of the out-of-plane bias field angle[6].

Here we study the nature of the spin-wave modes excited in a square nanomagnet (having the side in the range 200-400nm) where the current is injected via a nano-aperture located in the center of the device (the diameter of the nano-aperture is between 30 and 40 nm). We numerically solved the Landau-Lifshitz-Gilbert-Slonczewski equation [7], where the effective field includes magnetostatic, exchange, external and Oersted fields. We study a Py free layer (Ms=$650x10^3$A/m, exchange constant $1.3x10^{-11}$ J/m, a damping parameter of 0.1) (we consider the fixed layer to be pinned along the +x direction) with an applied field of 500mT. In the present paper, we do not include thermal effects. In our numerical experiments we find a new scenario about the excited spin-wave modes. In particular, we observe non-stationary jumps between a soliton-like mode (where the magnetization below the nano-aperture is reversed with respect to the initial equilibrium configuration) and a small-angle precessional mode. Figure 1 shows the temporal evolution of the components of the normalized average magnetization (x-top, y- center, z-bottom) computed for a current density J=$1x10^8$ A/cm^2. As can be observed in the top figure, the x component of magnetization undergoes a quasi-periodic jump around zero. When the magnetization is in the proximity of the value +1, the output power tends to be very small. In the opposite case, we observe the excitation of spin-wave modes having a frequency close to 20 GHz, a value which lies below the frequency of ferromagnetic resonance (22.7GHz), and thus exhibits a non propagating character. The jumps between the two states described above occur via a quasi-periodic motion of the inner domain from the center either to the top(figure 2, left) or to the bottom (figure 2 right) part of the device or in the bottom part of the device.

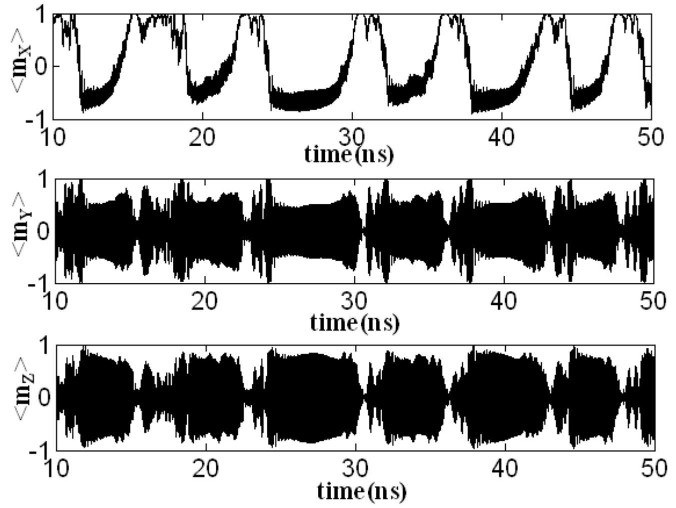

Figure 1: Temporal evolution of the x (top) – y (center) – z (bottom) components of the average H=500mT and J=10^8 A/cm^2.

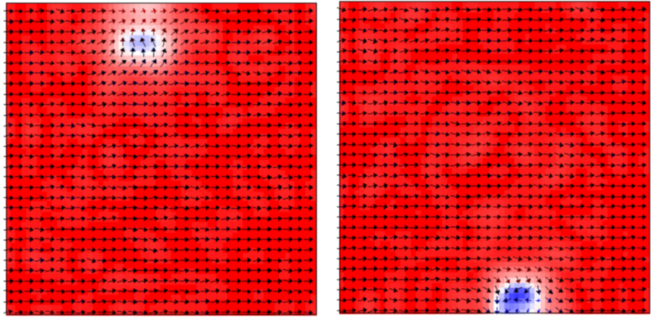

Figure 2 Mechanism of expulsion of the domain nucleated in the center of the device (left: expulsion in the top; right: expulsion in the bottom).

References

[1] S. I. Kiselev, et al. *Nature* **425**, 380-383 (2003).
[2] I. N. Krivorotov, et al. *Science* **307**, 228-231 (2005).
[3] K. V. Thadani, et al. *Phys. Rev. B* **78**, 024409 (2008).
[4] J. C. Slonczewski, J. Magn. Magn. Mater. 195, L261 (1999).
[5] A. Slavin and V. Tiberkevich, Phys. Rev. Lett. 95, 237201 (2005).
[6] G. Consolo et al., Phys. Rev. B 78, 014420 (2008).
[7] G. Finocchio, et al. *Phys. Rev. B* **76**, 174408 (2007).