Time-frequency characterization of magnetization dynamics in spin-torque oscillators

Giulio Siracusano[1], Giovanni Finocchio[1], Aurelio La Corte[2], Luis Torres[3], Bruno Azzerboni[1]

We first introduce a time-frequency characterization of magnetization dynamics driven by spin-polarized current in spin-torque oscillators. It is based on the continuous wavelet transform, with a systematic identification of the scale set $\{s_i\}_{i=1...N}$. We use the complex Morlet [1] wavelet ψ, this yields the corresponding wavelet family function $\psi_{u,s}$:

$$\psi_{u,s} = \frac{1}{\sqrt{s\pi f_B}} e^{j2\pi f_C\left(\frac{t-u}{s}\right)} e^{-\frac{1}{f_B}\left(\frac{t-u}{s}\right)^2} \quad (1)$$

where s and u are the scale and translation parameter, respectively, while f_C and f_B are characteristic parameters [1]. This wavelet-based approach generalizes the micromagnetic spectral mapping technique and, together with micromagnetic simulations, can be used to characterize the spin-torque oscillator dynamics completely. It is able to reproduce the frequency and power modulation claimed in stochastic theory developed by Kim in Ref. [2].

We reproduce the time-frequency behavior of measurements reported in [3] of the real-time voltage signal captured by a microwave storage oscilloscope. The device under investigation is a nanoscale spin valve Py(4nm) (free layer) / Cu(8nm) / Py(4nm) (pinned layer) / $Ir_{20}Mn_{80}$(8nm) (Py=$Ni_{80}Fe_{20}$) exchange biased with elliptical cross sectional area of $130\,\text{nm}\times 60\,\text{nm}$. We consider an applied current I=4.5mA and external field H=60mT. The power spectra shows two main frequencies f_{P1}=3.9GHz and f_{P2}=4.6GHz (for a signal of 20ns, these two modes are also measured at second scale), performing the Fourier transform with a window time of 4ns it can be observed either P_1 or P_2, this result shows the non-periodic origin of this magnetization precession (see fig. 6 in Ref[3]). Those results have been confirmed by our wavelet analysis as displayed in Fig 1. It shows the wavelet scalogram (arb. units) computed for the voltage signal of Fig. 6 in Ref.[3]. We use the following parameters: a set of scale parameters with N = 22 elements, f_B = 300 and f_C = 1. As can be noted, the results of our computations are consistent with the data displayed in Fig. 6 of Ref. [3]. Indeed the wavelet scalogram can show much more details, for example the decreasing of the output power of microwave signal close 16ns and the presence of the P_2 mode in 9-14 ns.

Finally, we performed a complete micromagnetic study of the non-stationary magnetization dynamics as function of field amplitude and angle, current and temperature. Our simulations take into account current-induced motion of not only the free but also the pinned ferromagnetic layer of the spin valve[4].

Our main results are: (i) exist magnetization oscillations with thermally-induced mode hopping behavior at the nanosecond time scale below a sub-critical current; (ii) a non-stationary behavior can be observed for non-collinear configuration of magnetization of pinned and free layer; (iii) as the field amplitude increases the frequency of two excited modes tend to be closer and, for a critical value of current, a single mode dynamics is driven (large amplitude magnetization oscillation).

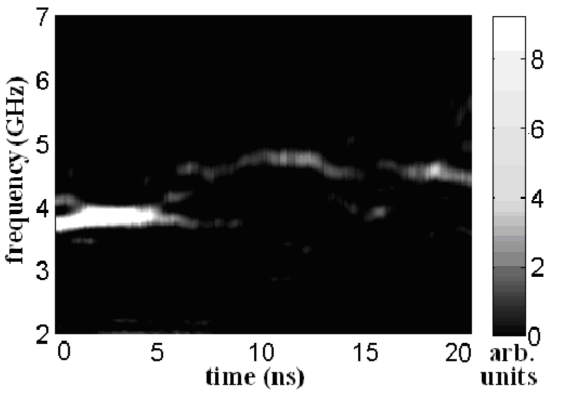

Fig. 1- Wavelet scalogram computed for the time-trace displayed in Fig. 6 of Ref. [2].

A complete dynamical stability diagram will be presented in the full paper.

[1] Department of Fisica della Materia e Ingegneria Elettronica, University of Messina, Salita Sperone 31, 98166 Messina Italy.
E-mail: gsiracusano@unime.it (Corresponding Author).
[2] Department of Informatic Engineering and Telecommunications. University of Catania. Viale Andrea Doria, 6 – 95125 Catania, Italy.
[3] Department of Física Aplicada, Universidad de Salamanca, Plaza de la Merced, Salamanca 37008, Spain.

REFERENCES

[1] A. Teolis, Computational signal processing with wavelets, Birkhauser, 1998.
[2] J.-V. Kim, *Phys. Rev. B* **73**, 174412 (2006).
[3] I. Krivorotov, N.C. Emley, R.A. Buhrman, D.C. Ralph, *Phys. Rev. B* **77,** 054440 (2008).
[4] G. Siracusano, G. Finocchio, I. N. Krivorotov, L. Torres, G. Consolo, B. Azzerboni, *J. Appl. Phys.* **105,** 07D107 (2009).