Intrinsic and Thermal Activated Linewidths of Spin-Transfer-Driven Vortex Self-oscillations

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Abstract

Narrow linewidth spin transfer driven vortex self-oscillations in Py/Cu/Py spin valves of elliptical cross section (160 nm x 75 nm) are investigated by means of micromagnetic simulations. "GPmagnet", a high performance GPU based micromagnetic package, is used for this purpose, allowing for 100 KHz spectral resolution at reasonable computational time. The variation of the linewidth with applied current ($10*10^7$ A/cm^2 < J < $20*10^7$ A/cm^2) is analyzed in the temperature range 0 K < T < 300 K. Linewidths around 1 MHz are found at T = 0 K. At T = 300 K, linewidths remain below 2 MHz for J < $16*10^7$ A/cm^2, whereas for larger currents the presence of two oscillation modes lead to a further linewidth increase.

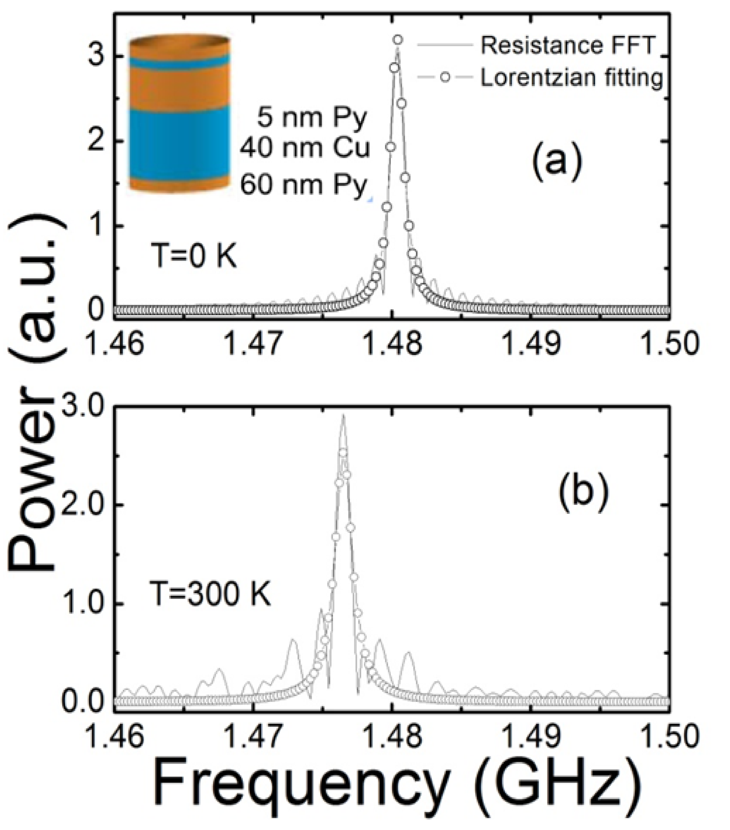
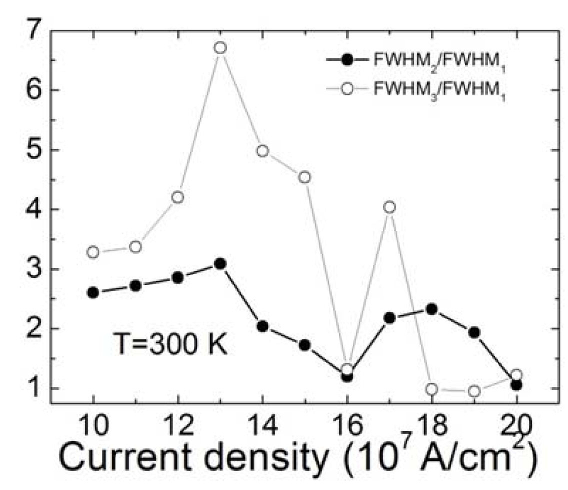


Fig. 1. Linewidth (solid line) for J= $10x10^7$ A/cm^2 together with lorentzian fitting (dotted line) at (a) T=0 K and (b) T=300 K. Inset of Fig 1(a): sketch of the spin-valve.

Results and discussion

As it was to expect for a non-linear STNO the thermal noise generates an increasing in the linewidth. As it can be observed by comparing Figs. 2(a) and 2(c), the orbits of the average magnetization are preserved in spite of the thermal activation so that the linewidth remains below 1.5 MHz as observed in experiments. The vortex oscillator in the spin valve shows itself as a robust oscillator against thermal noise for a range of current. The magnetization trajectory in the thin layer (Fig 2 (d)) differs significantly with respect to the T=0 K case (Fig. 2(c)). In particular, the averaged M_x component for T=300 K expands towards positive (less negative) M_x values due to the thermal activation. In Fig. 3 the dependences of linewidth and peak frequency on current and temperature are presented. In Fig 3(a), when increasing the current, a slight increase in the linewidth is observed up to currents around $16*10^7$ A/cm^2. This increase is due to the modification of the dynamics in a similar way to what we comment regarding Figs. 2(a-d). The general characteristics of the dynamics are preserved although the orbits are noisier. we have two oscillation modes present. These modes appear as a result of the complete analysis of the whole device and the use of the back torque. They are not thick-layer or thin-layer isolated modes but *"coupled device modes"*. The jump to the second mode depends on the thermal noise (different computational realizations can give rise or not to the jump) and also on the time window used in the computation. The jump time scale is the same as measured in those devices at zero bias field [V. S. Pribiag, G. Finocchio, B. J. Williams, D. C. Ralph, R. A. Buhrman, "Long timescale fluctuations in zero-field magnetic vortex oscillations driven by dc spin-polarized current", *Phys. Rev. B*(*R*), 80, 180411, 2009]. We have used a time window of 10^{-6} seconds for the fitting, choosing always realizations where the two modes are present. In a real experiment the window time is very large so that we think that both modes will be always present. In any case, for J > $15x10^7$ A/cm^2, an analysis of the thermal noise contribution to linewidth generation cannot be carried out in terms of analytical theories. we are dealing with highly non-uniform vortex configurations so that analytical theories are not even valid to describe single mode dynamics like in the case of Figs. 3(a-b). Nevertheless, linear behavior seems to be present in Fig. 3(a) for T < 140 K and also a lowering in frequency with temperature is detected.



We have also analyzed the second and third harmonic in the frequency spectra of the vortex STNO in order to check the recent study of Quinsat *et al.* [11]. In a nonlinear resonator, there is a relation between the corresponding linewidth of the nth harmonic and the linewidth of the main mode. In particular, in a non-isochronous oscillator the relation for the linewidths of higher harmonics are smaller than predicted in isochronous oscillators. In fact, non-isochronous auto-oscillators like STNOs are expected to show an increase in the linewidth with the harmonic order. This increase for the nth harmonic (Df_n) for a non-isochronous STNO is shown to be in the range $nDf_1 < Df_n < n^2Df_1$ [11].

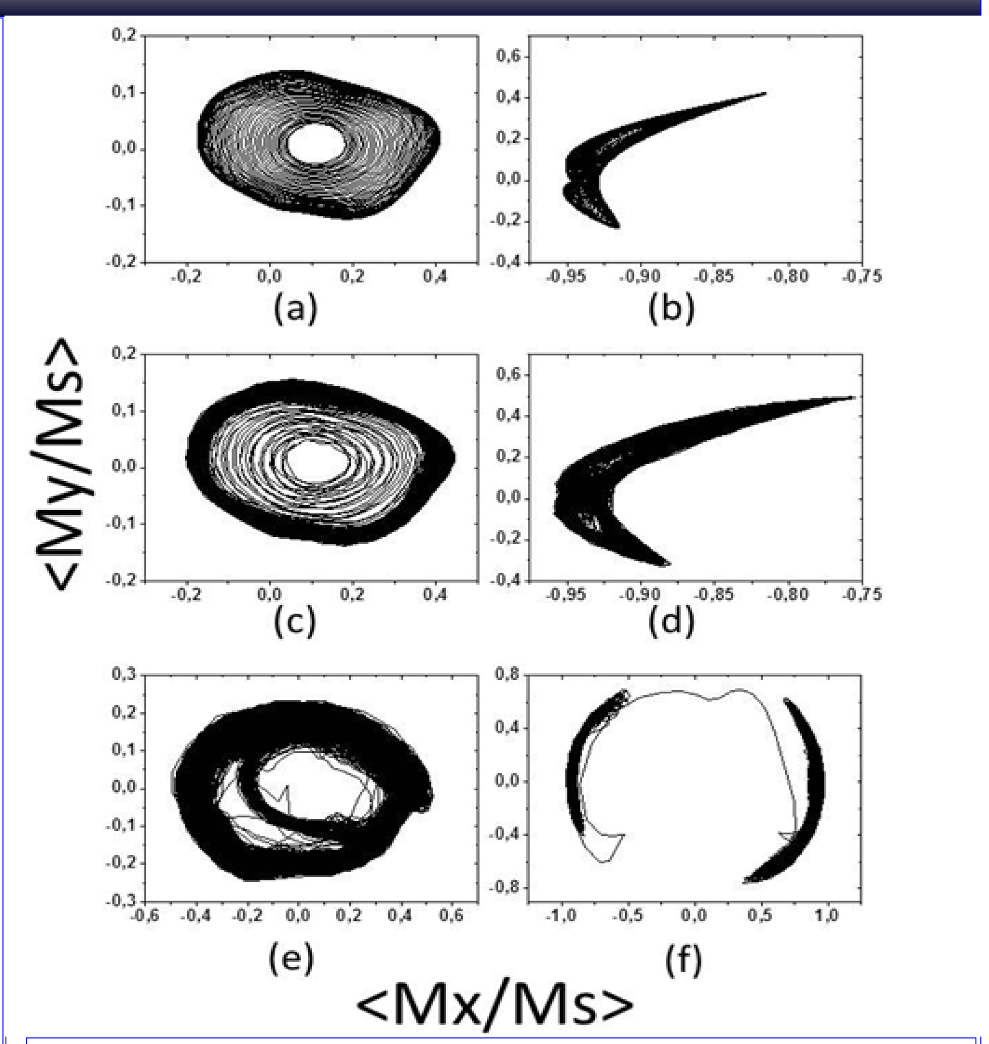


Fig. 2. M_x versus M_y trajectories for thick (a, c, e) and thin (b, d, f) Py layers. Current density is J= $10\ 10^7$ A/cm^2 in (a-d), T= 0 K in (a-b) and T= 300 K in (c-d). Current density is J= $16\ 10^7$ A/cm^2 and T= 300 K in (e-f).

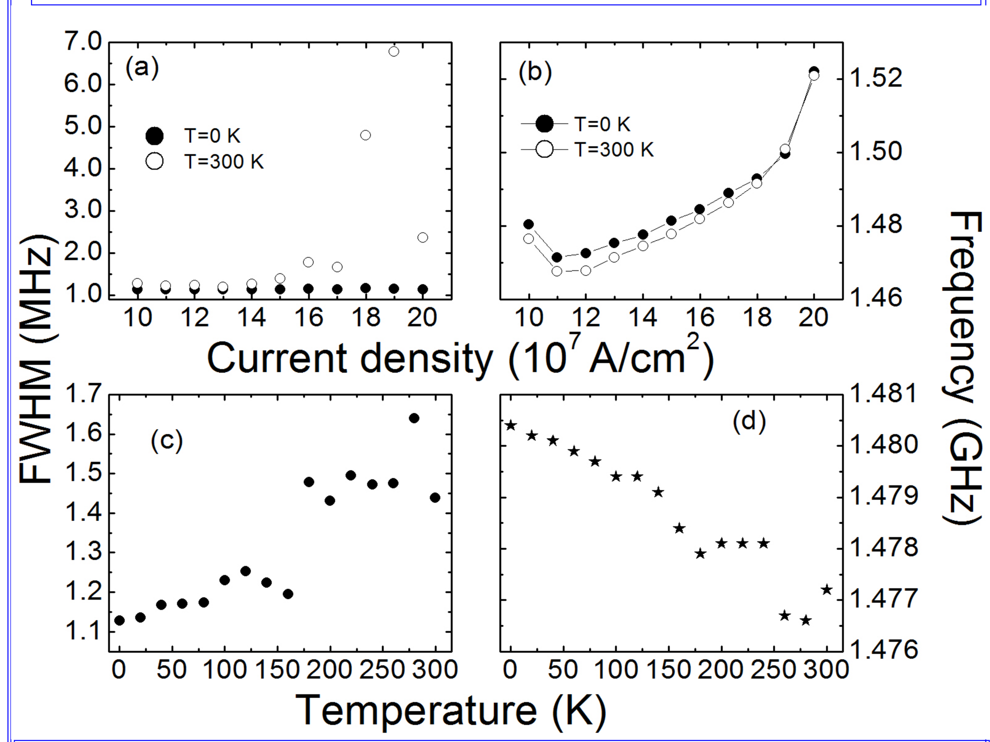


Fig. 3. Dependence of linewidth and frequency on temperature and current density. (a) Linewidth and (b) frequency for J ranging from $10x10^7$ A/cm^2 to $20x10^7$ A/cm^2 at T = 0 K and T = 300 K. (c) Linewidth and (d) frequency for J = $10x10^7$ A/cm^2 and temperature ranging from T = 0 K to T = 300 K.

Conclusions

In summary, we have carried out a detailed analysis of spin valve vortex STNOs showing that several device coupled modes can be present depending on temperature and applied current. When just one mode is excited, the STNO shows linear linewidth dependence for low temperatures.

References

[1] G. Finocchio, V.S. Pribiag, L. Torres, R. A. Buhrman et al., Appl. Phys. Lett. 96, 2010, 102508.
[2] V. S. Pribiag, I. N. Krivorotov, G. D. Fuchs, et al. Nat. Phys. vol. 3, 2007, pp. 498-503.
[3] www.goparallel.net; L. Lopez-Diaz, D. Aurelio, L. Torres, E. Martinez, et al. "Micromagnetic simulations using Graphics Processing Units" J. Phys. D: Appl. Phys. vol. 45, 2012, 323001 (17pp).
[4] M. Carpentieri, L. Torres and E. Martinez. IEEE Trans. Mag. vol 45(10), 2009, pp. 3426-3429.
[5] M. Quinsat, V. Tiberkevich, et al., Phys. Rev. B, Condens. Matter, vol. 86, 2012, 104418. (2012)

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