Micromagnetic Modeling of Telegraphic Mode Jumping in Microwave Spin Torque Oscillators

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Abstract—The time domain stability of microwave spin torque oscillators has been investigated by systematic micromagnetic simulations. A model based on internal spin wave reflection at grain boundaries with reduced exchange coupling was implemented and used to study the oscillator under quasi-stable operating conditions. Telegraphic mode jumping between two operating frequencies was observed in the time domain with characteristic dwell times in the range of 10-100 ns. The results are in good agreement with experimental findings.

Keywords—telegraphic mode jumping, micromagnetic simulations, microwave oscillators, spin transfer torque

I. RESULTS AND DISCUSSION

Spintronic devices are interesting alternatives to provide novel memory and logic functionality as well as microwave generation. These device are based on a stack of thin magnetic layers and have a very small footprint, e.g. compared to advanced CMOS devices and hence they can be integrated into the CMOS back-end-of-line processing. In spin torque oscillators (STOs) for microwave application the frequency is tuned by a DC current flowing into a nano-contact with diameter less than 100 nm. The current-frequency relation typically shows non-linear regions of operation as well as separated modes or frequency jumps, as shown in Fig. 1. In our previous work a model based internal spin wave reflection, due to reduced exchange coupling at grain boundaries, was proposed and could successfully reproduce a wide body of experimental observations [1]. In this work, for the first time, we use systematic simulations in the GPU accelerated micromagnetic software MuMax³ to study the time domain stability of the different frequency modes [2]. The simulations included a stochastic thermal field (T = 300 K) that acts on the individual micromagnetic spins. A characteristic telegraphic switching was observed for DC currents that correspond to abrupt frequency jumps. Fig. 2. shows simulations of 1 µs duration with four different seeds to the pseudorandom thermal field generator. In all cases, two frequency modes are observed in the power spectrum. By plotting the total oscillator energy density ($E \propto m \cdot B_{eff}$) vs. simulation time it was found that the two frequency modes are excited in a telegraphic manner and hence do not co-exist in time. Typical dwell times in the different modes are in the range of ten to hundred ns. These results in are in good agreement with our previous experimental work [3]. In our full paper we have analyzed the telegraphic mode jumping for a set of devices with different grain and exchange configurations and for different applied magnetic fields. Analysis of this data reveals several additional mode transitions, in particular at high current, above 30 mA, where the stable frequency, cf. Fig.1, seems to break up. In these situations shorter dwell times are observed.

Fig. 1. Simulated output power (dB/Hz) vs. driving DC current for a 100 nm diameter STO, Co(8)/Cu(8)/NiFe(4.5nm) stack, showing non-linear behavior and mode jumping due to internal spin wave reflection in grain structure. The simulations were performed for 10 kOe applied external field (70° angle) and T = 300 K.

Fig. 2. Time domain representation of oscillator energy density at DC current 27.75 mA, for different thermal field seeds showing two mode telegraphic jumping. The colored lines are moving averages over 100 time steps

REFERENCES

