Resonant expulsion of a magnetic vortex by spin transfer: towards a new type of RF detector

S. Menshawy[1,2,*], **A.S. Jenkins**[2], **K.J. Merazzo**[3,4], **L. Vila**[3,5], **R. Ferreira**[6], **M.-C. Cyrille**[3,4], **U. Ebels**[3], **V. Cros**[2], **P. Bortolotti**[2], **J. Kermorvant**[1]

[1] Thales Communications & Security

[2] *Unité Mixte de Physique CNRS Thales, Univ. Paris-Sud, Université Paris-Saclay, Palaiseau, France*

[3] *Univ. Grenoble Alpes, CEA, CNRS, SPINTEC, F-38000 Grenoble, France*

[4] *Univ. Grenoble Alpes, CEA-LETI MINATEC, F-38000 Grenoble, France*

[5] *Univ. Grenoble Alpes, CEA, INAC, NM, F-38000 Grenoble, France*

[6] *International Iberian Nanotechnology Laboratory (INL), 4715-31 Braga, Portugal*

samh.menshawy@thalesgroup.com

Many studies on spin transfer effects have led to considerable progress in the field of spintronics, including opportunities for new features to radiofrequency devices (rf), such as generating an RF signal associated to the magnetization dynamics excited by spin transfer. These devices, called spin transfer nano-oscillators (STNOs) are based on the excitation of precession modes in frequency ranges from less than 100 MHz up to tens of GHz [1]. Among the different configurations studied, the precession of a vortex core maintained by spin transfer is of particular interest because, in addition to being a model for identifying the origin of spin transfer torques [2], those STNOs with vortices have excellent signal characteristics, i.e, large output power and small linewidth [3,4].

One potential new feature of STNO is the radio frequency detection. Indeed, when a RF current is injected into the sample, the magnetization dynamic induced by torques associated with the rf current generates a rectification voltage called spin diode effect which is related to the mixture of the variation of the resistance and the oscillations of the applied rf power. Such effect was observed in the ferromagnetic resonance modes in uniform magnetic tunnel junctions [5] with a higher sensitivity to the existing semiconductor based detectors, i.e., Schottky diodes [6,7].

In this study we focus on systems having a magnetic vortex which allows the detection of rf signals in a frequency range between 100 MHz and 1 GHz. Our experimental study focuses on magnetic tunnel junctions with a magnetic vortex in the free layer of NiFe. We were able to identify two regimes of vortex dynamics depending on the rf current amplitude. At low I_{rf} (typically less than 1 mA), the mode of the gyrotropic vortex core is excited resonantly by rf torques. This vortex motion is converted by spin-diode effect to a voltage (see Fig. 1a). The amplitude of the radius oscillations (and thus the detected voltage) can be compared quantitatively to analytical predictions and micromagnetic simulations [8]. At stronger current, and in presence of a dc current (to partially compensate the damping), a new phenomenon is observed: the resonant expulsion of the vortex core. Indeed, in this case, the radius of the vortex core excitation becomes larger than the tunnel junction radius and thus the system enters from a vortex configuration to a substantially uniform configuration when the frequency of the rf current injected approaches the frequency of the vortex core resonance mode (see Fig. 1b). This phenomenon is accompanied by a sudden and significant change in resistance (and therefore the voltage) of the device. When the rf frequency is sufficiently far from the vortex core resonance, the free layer return to it vortex configuration. This effect offers an interesting alternative to the spin diode effect for detecting rf signals because the sensitivities are potentially much higher and moreover it allows to consider the development of real time thresholds detectors [9]. We studied how the expulsion frequency of the vortex core varies as function of magnetic field (from -8000 to 8000 Oe), the applied DC current (0 to 10 mA) and the geometry of STNO (diameter between 100 and 500 nm). In addition, we also considered the development of radio frequency spectrum occupancy detector by connecting in parallel multiple STNOs having different diameters and therefore different frequencies, in order to cover the desired frequency band. This study is also based on micromagnetic simulations and in particular the use of a specific solver mode to accurately predict the vortex resonances frequencies in the studied experimental system but also in more complex systems.

On Fig. 2 we present the detected voltage as a function of the rf source frequency when three STNO's are connected in parallel, showing three vortex core expulsions, one for each device. The respective amplitudes of the three signals are different because the three studied STNOs have quite different TMR signals. Furthermore, the bandwidth of the rf signal detected depends on the characteristics of each oscillator. A better understanding of the physical mechanisms associated to the vortex core expulsion together with a more systematic analysis of several STNOs should allow us to further control this characteristic of the detector. The sensitivities obtained are in the order of 15-20 V / mW.

In summary, the expulsion of the vortex core in STNOs is an approach that offers better voltage characteristics than the rectification effect, which make it very promising for the instantaneous rf detection. The following of the study aims at better understanding the vortex core expulsion, in order to achieve an advanced integrated rf detector prototype covering a frequency range from 100 MHz to 1 GHz.

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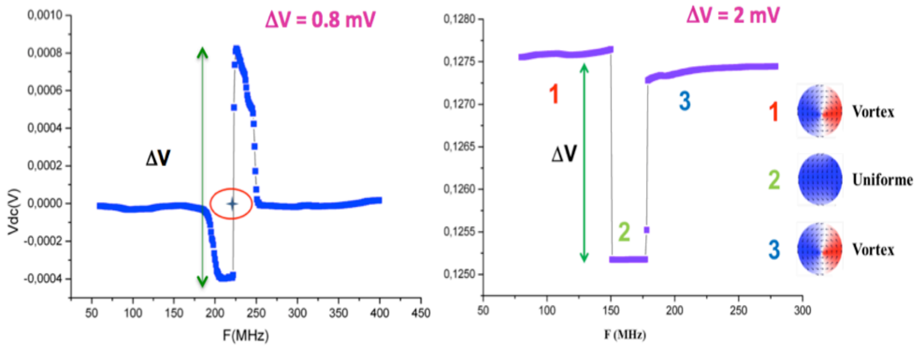

Figure 1. a) Rectification effect detected for a STNO with one vortex, of diameter D = 400 nm at I_{DC} = 0 mA, P_{RF} = -4 dBm and H = -1700 Oe b) Vortex core expulsion detected for a STNO of diameter D = 500 nm at I_{DC} = 6 mA, P_{RF} = -4 dBm and H = -2000 Oe

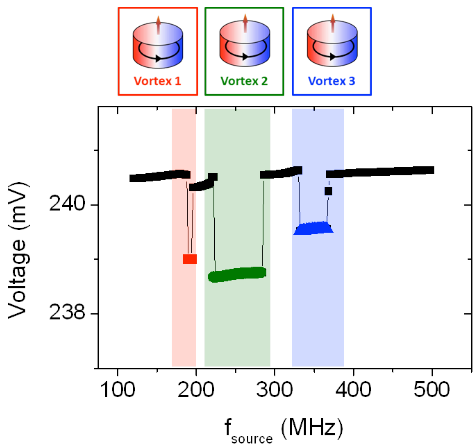

Figure 2. Three vortex core expulsions for three STNOs with one vortex, of diameter D = 500 nm (red), 400 nm (green) and 300 nm (blue).