Evolution of synchronization in spin torque oscillators

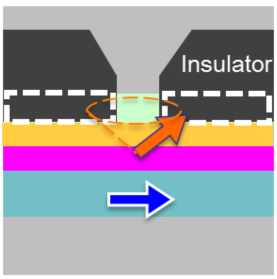
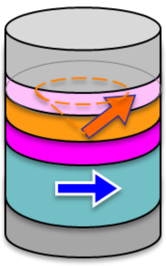
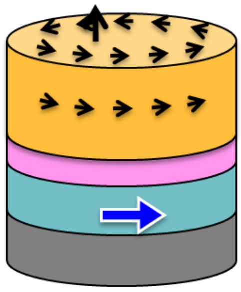
S. Tsunegi, K Yakushiji, A. Fukushima, S. Yuasa, and H. Kubota
(AIST, Spintronics Research Center, Tsukuba, Japan)

Spin-torque oscillator (STO)[1] has attracted much interest from a viewpoint of application to a nano-scale oscillator because of the wide range frequency tunability and high compatibility with semiconductor CMOS circuits. For the practical use, a lot of work has been done to improve emission power and narrow linewidth of emission spectrum. The studies so far have been conducted from mainly two aspects. The one is material development for STO devices such as MgO barrier and suitable free layers. The other is system development using a magnetic or electric interaction between multiple STOs or between an STO and external rf signals.

In the first approach, we carried out serial studies with STOs developed using MgO-based magnetic tunnel junctions (MTJs), resulted in the emission power increase up to 0.1 μW.[2] The power increase was a dramatic leap from a few pW reported in the initial GMR based STO[1]. Recent studies have revealed that STOs having perpendicularly magnetized free layer[3] and sombrero-type free layer[4] exhibit further increased emission power up to a few μW (Table I). Furthermore, quite recently, an emission power over 10 μW has been achieved in a vortex-type STO with a narrow linewidth of 100 kHz. [5,6] The value of 10 μW is as large as that of commercial crystal oscillators.

In the second approach, S. Kaka[7] and F. B. Mancoff[8] demonstrated the reduction of linewidth in two-point-contact STOs in 2005. They realized the synchronization between STOs' precession, where precession frequencies drew each other through spin-wave and dipole-diple interactions. W. H. Rippard demonstrated electrical synchronization of STO precession to a large rf current injected from an external signal source.[9] In this case the synchronization was induced by rf spin torque. However, in the early stage of synchronization investigation, it was impossible to realize the electrical synchronization among STOs because of very low emission powers generated by the STOs.

Table I Several types of STOs and its features.

Type	Sombrero[4]		Perpendicularly Magnetized free layer[3]	Vortex[5,6]	
					
Size	4 μm		120 nm (250 nm)	300 nm	
Power μW	2.4	0.1	0.5 (2.0)	1.4	3.4
Frequency GHz	4	11	6 (7.0)	0.23	0.48
Q factor (freq./linewidth)	330	3200	130 (2300)	6400	210
Features	High power, high Q		Small, high power	High Q, Low frequency	

It is at the very moment that the two approaches are merged. As mentioned, the recent progress of the STO performance has enabled the electrical synchronization among STOs. Indeed, we demonstrated the self-synchronization in a vortex-STO,[10] where the vortex gyration was synchronized to rf currents generated by the STO itself.[11,12] In such system, the phase difference between the STO and the reinjected rf current gives remarkable influence on the gyrotropic motion of the vortex. The fact indicates that the phase difference is essential to the electrical mutual synchronization as theory predicted.[13] By taking account of the effect of the phase difference, we have finally demonstrated the electrical mutual synchronization among STOs. The emission power and linewidth were successfully improved as shown in Fig. 1.[14,15] In the presentation, we report our latest results on the vortex-STOs as well as their electrical mutual synchronization.

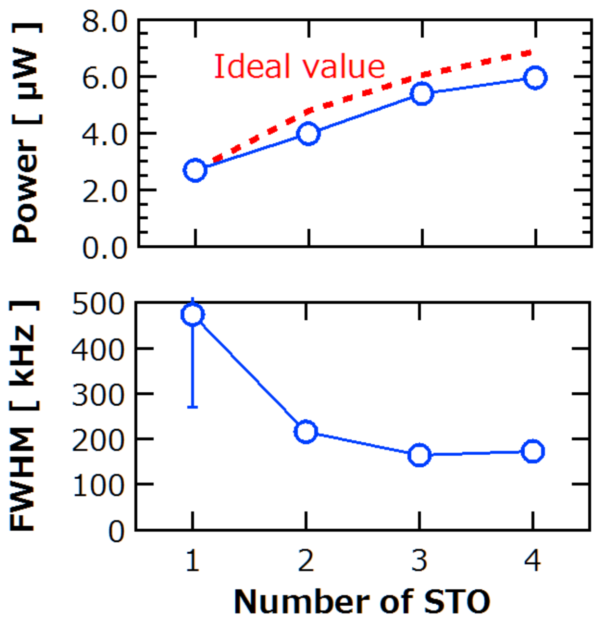


Figure 1 The STO number dependence of emission power and linewidth.

<Reference>
1) S. I. Kiselev, et. al, Nature 425, 380 (2003).
2) A. M. Deac, et. al., Nat. Phys. 4, 803 (2008).
3) H. Kubota, et. al., Appl. Phys. Express 6, 103003 (2013).
4) H. Maehara, et. al., Appl. Phys. Express 6, 113005 (2013).
5) S. Tsunegi, et. al., Appl. Phys. Express 7, 063009 (2014)
6) S. Tsunegi, to be submitted
7) S. Kaka, et. al., Nature 437, 389 (2005).
8) F. B. Mancoff, et. al., Nature 437, 393 (2005)
9) W. H. Rippard, et. al., Phys. Rev. Lett. 95, 067203 (2005)
10) G. Khalsa , et. al., Appl. Phys. Lett. 106, 242402 (2015)
11) S. Tsunegi, et. al., Sci. Rep.. (to be published).
12) S. Tsunegi, et. al., The 13th MMM-Intermag (2016)
13) Y. Zhou , et. al., J. Appl. Phys. Lett. 101, 09A510 (2007)
14) R. Lebrun, et. al., arXiv:1601.01247
15) S. Tsunegi, et. al., The 63rd JSAP Spring Meeting (2016)