Spin-wave mediated mutual synchronization and phase tuning of spin Hall nano-oscillators

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Generation and manipulation of propagating spin waves (PSWs) in magnetic multilayer systems have opened new frontiers for magnonics and spin-wave-based computing [1]. The precise control of frequency and phase of PSWs in nanoscopic CMOS compatible systems is of high importance for emerging applications such as reservoir computing and Ising machines [1,2,3]. Recently, spin-orbit torques have been shown to drive PSW auto-oscillations in perpendicular magnetic anisotropy (PMA)-based nano-constriction spin Hall nano-oscillators (SHNOs) [2]. Due to their long-range propagation, the mutual synchronization of SHNO, previously demonstrated in 1D chains [4] and 2D arrays [5], can also benefit from these PSWs.

In this work [6], we report spin-wave mediated variable-phase mutual synchronization in nano-constriction SHNOs, enabling both in-phase and anti-phase synchronization of their individual auto-oscillatory modes, Fig. 1a. Using W/CoFeB/MgO trilayers with PMA, SW auto-oscillations were observed and characterized via electrical measurements and phase-resolved micro-focused Brillouin light scattering (µ-BLS) microscopy. Electrical power spectral density measurements on W/CoFeB/MgO samples (Fig. 1b) with 500 nm spacing reveal distinct synchronization regimes, including constructive (in-phase) and destructive (anti-phase) interference patterns. These patterns (denoted as regions II and III) can be further controlled through the applied magnetic field and direct current. In contrast, in-plane magnetized W/NiFe systems (Fig. 1c) showed no phase control due to the absence of PSWs. Phase-resolved µ-BLS confirms both in-phase and out-of-phase states, providing conclusive evidence of long-range SW coupling. Micromagnetic simulations corroborate the experimental results and highlight the role of SW dispersion in phase tuning. Additionally, voltage-controlled magnetic anisotropy (VCMA) is proposed for localized phase control, offering a scalable mechanism for phase-tunable SHNO arrays. These findings hold significant promise for SW-based Ising machines, neuromorphic computing, and reconfigurable logic devices [1,3,6].

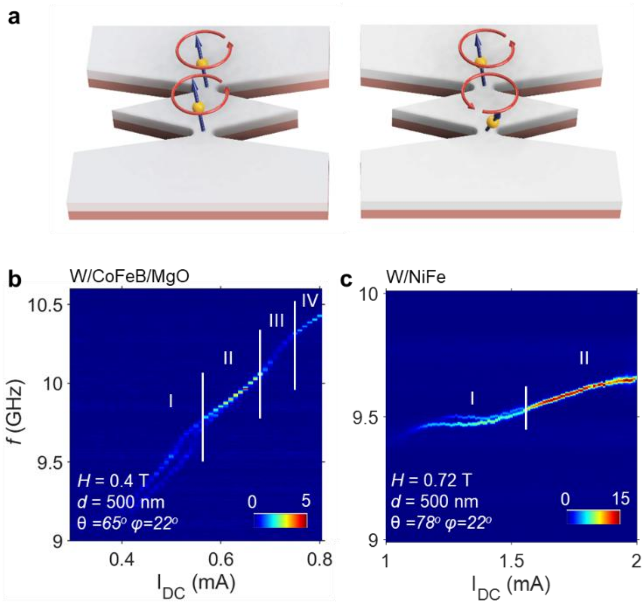

Figure 1. (a) Schematic of in-phase and out-of-phase mutual synchronization between two SHNOs. Power spectral density as a function of applied current (IDC) for two mutually synchronized SHNOs fabricated using (b) PMA based W/CoFeB/MgO thin films and (c) in-plane magnetized W/NiFe thin films.

References

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