2nd Transnational Round Table on Magnonics, High-Frequency Spintronics, and Ultrafast Magnetism

Recent advances in spin-wave-mediated mutual synchronization of spin Hall nano-oscillator networks

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The generation, propagation, and manipulation of magnons (quanta of spin waves) allow the long-range transfer and processing of digital and analogue information, laying the groundwork for magnonics [1-2] and spin-wave computing [3]. In this regard, spin Hall nano-oscillators (SHNOs) are an emerging class of spintronic devices that generate propagating spin waves over long distances and have attracted significant interest due to their distinctive features, including extremely small dimensions (down to 10 nm) [4], strong mutual synchronization [5-7], voltage-controlled tunability [8], and memristive gating capabilities [9]. These characteristics make SHNOs attractive for applications such as wireless communication, ultra-fast spectrum analysis, neural networks, and oscillator-array based Ising machines. In this talk, I will first discuss our recent work on spin-orbit torque (SOT)-driven auto-oscillations of propagating spin wave modes in two mutually synchronized W/CoFeB/MgO based SHNOs. These modes enable long-range coupling and offer control over their phase, which is critical for device applications as well as fundamental understanding. Through electrical measurements and phase-resolved micro-focused Brillouin light scattering microscopy (μ-BLS), we demonstrate that the phase of mutual synchronization can be adjusted by modulating the drive current [10].

Furthermore, although SHNO arrays of up to 100 nano-oscillators have been demonstrated, the maximum number of mutually synchronized SHNOs remains limited to N = 64 [6]. Since dipolar coupling scales with the cube of the inverse distance, narrower SHNOs can be positioned closer together, facilitating easier synchronization. I will present our recent breakthrough results on mutual synchronization of ultra-large mutually synchronized 2D SHNO networks of up to N = 105,000, fabricated from an optimized material stack consisting of W-Ta/CoFeB/MgO [4, 11]. These SHNO networks exhibit significantly improved microwave signal properties. To directly visualize the auto-oscillations and the mutual synchronization, we use scanning micro-Brillouin light scattering (μ-BLS) microscopy and map out the spin wave intensity inside and outside of the arrays. The unexpectedly strong dependence of frequency-current tunability on array size is attributed to magnon exchange between nano-constrictions and magnon losses at the array edges, further supported by micromagnetic simulations and BLS microscopy [11]. Our results represent a significant step towards viable SHNO network applications in wireless communication and unconventional computing.

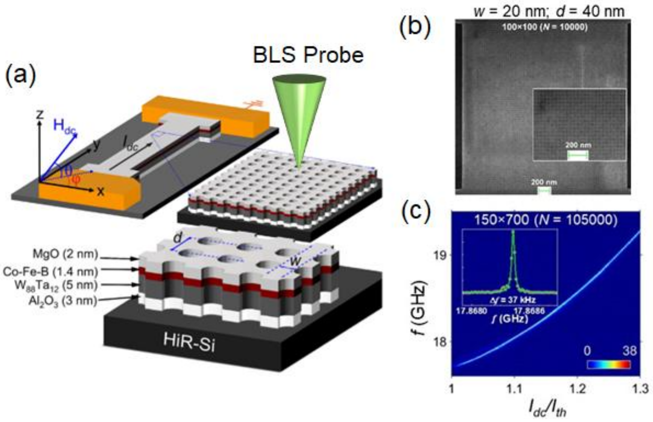

Figure 1. (a) Schematic of the SHNO arrays and their material stack, showing consecutive zoom-ins. The directions of the drive current and the applied field are indicated. The bottom cartoon shows the material stack and the nano-constriction width (*w*) and center-to-center separation (*d*). (b) SEM image of a 100×100 array made from 20-nm nano-constrictions. (c) Power spectral density *vs.* criticality (I_{dc}/I_{th}) for representative arrays with N = 105000 nano-constrictions (w = 10-nm).

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