Energy-Efficient Spin Hall Nano-Oscillators

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Energy-efficient materials are crucial for advancing spintronic devices. The main motivation for enhancing their functionality lies in reducing power consumption, improving thermal stability, increasing device lifespan, enabling miniaturization, and reducing environmental impact. Recently, nano-constriction-based spin Hall nano-oscillators (NC-SHNOs) have emerged as a versatile class of devices due to their straightforward fabrication, direct voltage gating control, laser heating capability, and propagating spin-wave-assisted mutual synchronization in one and two dimensions, with potential applications in Ising Machines [1-3]. In this talk, I will first present our findings on the magnetodynamic properties and magnetization auto-oscillations of ultra-narrow 10 nm wide single-NC SHNOs, fabricated from W-Ta/CoFeB/MgO stacks grown on various substrates and seed layers [4]. By optimizing the $W_{88}Ta_{12}$ alloy, using low-damping CoFeB, and achieving moderate perpendicular magnetic anisotropy, we have reduced the threshold current to 28 µA in the best devices. Additionally, I will discuss our recent work on self-spin orbit torque-driven magnetization auto-oscillations in single-layer magnetic Weyl semimetal (Co_2MnGa) based NC-SHNOs, operating at an ultra-low threshold current density of J_{th} = 6.2 × 10^{11} Am^{-2}, a factor of five lower than previous single layer NiFe report [5].

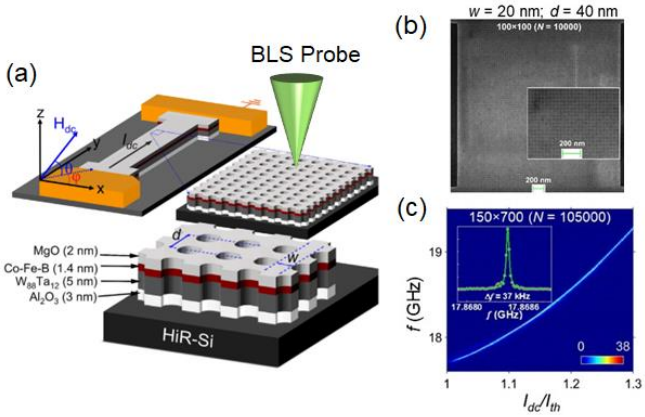

Figure 1. (a) Schematic of the SHNO arrays and their material stack, showing consecutive zoom-ins. The directions of the drive current and the applied field are indicated. The bottom cartoon shows the material stack and the nano-constriction width (*w*) and center-to-center separation (*d*). (b) SEM 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).

In the second part of my talk, I will present our results on the mutual synchronization of ultra-large 2D SHNO networks, with up to *N* = 105,000 synchronized nano-oscillators, fabricated from an optimized W-Ta/CoFeB/MgO material stack [6]. These SHNO networks demonstrate significantly enhanced microwave signal properties. To directly visualize the auto-oscillations and mutual synchronization, we utilize scanning micro-Brillouin light scattering (µ-BLS) microscopy to map the spin wave intensity both inside and outside the arrays. The unexpectedly strong dependence of frequency-current tunability on the array size is attributed to magnon exchange between nano-constrictions and magnon losses at the array edges, a phenomenon further supported by micromagnetic simulations and BLS microscopy. The state-of-the-art ultra-low operational current and mutual synchronization in these large SHNO networks offer an energy-efficient approach for scaling oscillator-based neuromorphic computing in linear chains and two-dimensional arrays.

References

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