Orbital Angular Momentum Driven Memory, Oscillators, and Terahertz Devices

R. Gupta,[1,2]
a: Department of Physics, University of Gothenburg, Gothenburg, Sweden;
b: Department of Physics, University of South Florida, Tampa, Florida, USA

The Spin Hall Effect (SHE) and its reciprocal effect enable magnetization control in spintronic devices such as spin–orbit torque (SOT) memory[1,2], spin Hall nano-oscillators (SHNOs)[3], terahertz emitters[4], and SOT sensors[5]. The SHE requires strong spin–orbit coupling (SOC) to efficiently convert charge current into spin current. Orbitronics extends this concept by exploiting orbital angular momentum (OAM), where the orbital Hall effect (OHE) can generate orbital currents substantially larger than spin currents, even in materials with weak SOC[6,7,8 9].

In this talk, I address three central questions in spin-orbitronics field: how to experimentally distinguish the OHE from the SHE despite their identical symmetry; whether orbital transport differs from spin transport; and whether large orbital Hall conductivity enhances device performance, especially in SOT SOT memory and SHNO devices.

We demonstrate pronounced damping-like orbital torques in low-SOC orbital layer (Nb and Ru) in Nb/Ni and Ru/Ni bilayers, including a sign reversal between Nb/Ni and Nb/FeCoB that confirms distinct OHE behavior. In SOT-MRAM device structures, Ru/Pt OHE layers provide a 30% increase in torque efficiency and a 20% reduction in switching current density compared to conventional Pt spin layer across 250 devices, with a thermal stability factor exceeding 60 K_BT and a projected data retention time of more than 10 years[10]. In SHNOs, orbital currents in Ta reduce the auto-oscillation threshold current (I_c) by 50% compared to Pt, as shown in Fig. 1, accompanied by a 20% enhancement in orbital torque, in agreement with theoretical predictions of orbital-to-spin conversion and the calculated OHC and SHC[11]. Finally, time-resolved terahertz emission measurements reveal superdiffusive orbital transport, evidenced by a 3 fs/nm delay in Ni/Ru structures[12].

These results establish orbital currents as a means to enable energy-efficient devices and position orbitronics as a powerful extension of spintronics.

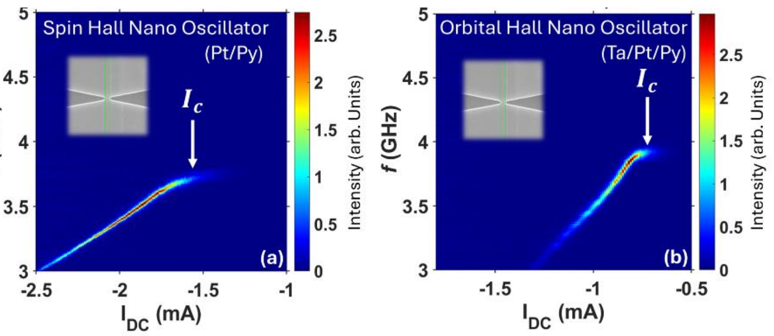

Fig. 1. Power spectral intensity (PSI) plot showing frequency as a function of applied direct current (I_{DC}) for nano-constrictions in (left) Pt/Py spin Hall nano-oscillator and (right) Ta/Pt/Py orbital Hall nano-oscillator. The inset shows a scanning electron microscope image of the respective oscillator with a width of 150 nm.

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