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Spin-orbit torque phenomena in complex oxide heterostructures

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Energy-efficient magnetic spin orbit torque nano-oscillators and coupled oscillator arrays are being explored for low-power neuromorphic computing systems [1, 2]. Commonly studied oscillator systems are mostly based on metallic bilayers of ferromagnet (FM)/ heavy metals (HM) (FM=CoFeB, Py and NM=Pt, Ta, W). I will discuss recent efforts to replace the metallic layers with complex oxides with coupled spin, electron and lattice degrees of freedom [2]. Large spin-charge conversion, low damping, and small resonance linewidth are essential constituents for the development of energy efficient oscillators. In this regard half-metallic perovskite ferromagnet, $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) films are studied as the magnetic free layers [3] combined with transition metal oxides such as iridates (e.g. IrO_2, $SrIrO_3$, *etc.*) and $NdNiO_3$ (NNO) as the spin-orbit torque layer providing potentially new functionality. For example, IrO_2 has a unique electronic structure, where the density of states near the Fermi level is dominated by only 5d electrons with strong spin-orbit coupling and large charge to spin conversion [4]. NNO exhibits a first-order metal-insulator transition near 200K in bulk. The onset of the metal-insulator phase transition is also accompanied by a complex E' type anti-ferromagnetic ordering in this material. We observe thickness and temperature dependent modulation of spin-charge conversion through the phase transition of NNO and harness the disorder in NNO to generate a pronounced enhancement of the inverse spin Hall effect signal at the transition temperature [5]. Finally progress towards an all-oxide nano-oscillator will be discussed. This work is supported by the U.S. Department of Energy under Grant No. DE-SC0019273.

[1] J. Grollier *et al.*, Nature electronics 3, 360 (2020).
[2] A. Hoffmann *et al.*, APL Materials 10, 070904 (2022).
[3] Sahoo et al., *Adv. Mater. Interfaces*, 2401038 (2025).
[4] Sahoo, Frano and Fullerton, Appl. Phys. Lett. 123, 032404 (2023).
[5] Sahoo, *et al.* submitted for publication (2025).

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