Emergent Spintronic Functionalities in Correlated Oxide Heterostructures

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Spintronics promises low-power, multifunctional electronics in which electron spin enables both logic and memory operations. Among the various proposed devices, spin transistors are particularly attractive for non-volatile computing. Key milestones toward their practical realization include the demonstration of large spin-valve effects and the achievement of efficient spin-charge interconversion, both of which are vital for energy-efficient operation. Perovskite oxides provide a versatile materials platform owing to their nearly matched lattice constants, which allow the fabrication of high-quality all-epitaxial heterostructures essential for coherent spin control in devices. These correlated oxides exhibit emergent functionalities, such as two-dimensional transport with strong spin–orbit coupling, metal–semiconductor transitions, topological states, and spin Hall effects, thereby offering unique opportunities for spintronics applications.

We first demonstrate a giant planar spin-valve effect in $(La_{0.67},Sr_{0.33})MnO_3$ (LSMO)-based spin-MOSFETs, where oxygen-vacancy engineering creates nanoscale Mott-semiconducting regions, yielding magnetoresistance ratios of ~140% [1] — over two orders of magnitude higher than those of conventional Si-based spin-MOSFETs. Second, we show highly efficient spin-to-charge conversion in the two-dimensional electron gas formed at the strongly correlated $LaTiO_{3+\delta}$ (LTO)/$SrTiO_3$ interface, achieving a record conversion efficiency (referred to as the inverse Edelstein length) of ~190 nm [2]. This performance originates from Rashba spin–orbit coupling combined with reduced spin scattering in correlated metallic LTO. Finally, in the Weyl ferromagnet $SrRuO_3$ (SRO), subtle oxygen-octahedral rotations generate spin Berry curvature that drives spin–orbit torque magnetization switching in a single-layer device [3]. Magnetization reversal occurs at current densities an order of magnitude lower than those required in conventional bilayer systems, without the need for heavy-metal layers.

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