Spintronics: A Pathway to Energy-Efficient Technology

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ABSTRACT

Spintronics utilizes both charge and spin degrees of freedom of electron, offering a pathway to faster, more energy-efficient information technologies. Hard disk drives (HDDs) remain a cornerstone of data storage technology, relying on magnetic materials to encode information densely and reliably. Advances in spintronics are now driving the next generation of HDDs, enabling higher storage capacity, faster access, and improved energy efficiency. Harnessing quantum materials—such as topological insulators, transition metal dichalcogenides, altermagnets, complex oxides etc—has opened new frontiers for controlling spin generation, transport, and manipulation. These materials exhibit strong spin–orbit coupling (SOC) and exotic interface phenomena that enable efficient spin–charge interconversion and robust spin currents, even at room temperature, paving the way for fast, low-power spin-based devices that go beyond conventional electronics. Understanding and engineering these interfacial effects are central to realizing next-generation spintronic devices. Recent advances in thin film fabrication, interface design, and manipulating spin-orbit coupling have revealed how quantum materials govern spin dynamics at the nanoscale. By coupling these mechanisms with materials possessing tailored spin textures, it becomes possible to achieve deterministic spin–orbit torques and low-power magnetization switching. This talk will highlight recent progress in exploring and engineering quantum materials for spintronic applications, emphasizing how interface control and spin-orbit coupling can be leveraged to design devices with enhanced spin-to-charge conversion efficiency. The integration of quantum materials into spin-based architectures not only deepens our understanding of condensed matter physics but also paves the way toward transformative technologies in dissipationless transport, nonvolatile memory, and quantum computation. Moreover, the interplay of SOC and magnetism in these systems can stabilize topological spin textures such as skyrmions. By harnessing these effects, spin–orbitronic quantum materials could bridge fundamental quantum physics and next-generation technology, transforming how information is processed and stored.