Quantum Sensing with Spin–Orbit-Coupled Surface States in Chalcogenides

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Quantum sensing exploits quantum coherence, spin–orbit coupling, and phase-sensitive transport phenomena to achieve enhanced sensitivity to external perturbations beyond classical limits. In this context, topological insulators (TIs) constitute a promising solid-state platform for quantum sensing, owing to their strong spin–orbit coupling and the presence of robust, spin-polarized topological surface states (TSS) [1].

This work explores Sb_2Te_3 topological insulator nanostructures as a basis for quantum sensing applications, focusing on their sensitivity to magnetic, electric, and thermal perturbations. Sb_2Te_3 thin films and hybrid ferromagnet/TI heterostructures were fabricated using scalable sputtering techniques, enabling systematic control of thickness, disorder, and interface quality [2]. Temperature-dependent electrical and thermoelectric transport measurements reveal the coexistence of bulk and surface conduction channels, with a crossover to surface-dominated transport at low temperatures. Magnetoconductance measurements show clear signatures of weak antilocalization, allowing the extraction of phase coherence lengths on the order of tens of nanometers, highlighting the robustness of quantum interference effects in these systems.

In ferromagnet/Sb_2Te_3 bilayers, magnetisation dynamics studied via ferromagnetic resonance demonstrate efficient spin pumping into the TI layer, with enhanced damping correlated with the temperature regime where TSS dominate conduction. These results evidence a strong coupling between magnetic excitations and spin–orbit-driven surface states, providing a direct quantum transduction mechanism between external magnetic stimuli and measurable electrical signals.

The demonstrated sensitivity of Sb_2Te_3 topological surface states to magnetic fields, temperature, and interfacial spin dynamics establishes these nanostructures as viable quantum sensing elements, compatible with solid-state integration and scalable fabrication [3]. This platform opens pathways toward compact quantum sensors for magnetometry, nano-thermometry, and field sensing, with relevance for both fundamental research and emerging quantum technologies.

References

[1] Degen, C.L.; et al., Rev. Mod. Phys, 89, (2017) 035002-29.
[2] Ferreira-Teixeira, S.; et al., ACS Appl. Electron. Mater. 4 (2022) 5789–5798
[3] Moreira, M.; Pires, A.L.; et al., Adv. Funct. Mater. 34(45) (2024), e2405057

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