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Superconducting spintronics with electron symmetry filtering and interfacial spin–orbit coupling

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Abstract-

Over recent years, the crossroads of magnetism and superconductivity have led to the emerging field of superconducting spintronics. A cornerstone of this venture is the generation of equal-spin triplet Cooper pairs in superconductor-ferromagnet hybrids, enabling long-range spin-polarized supercurrents and magnetic control over superconducting quantum states for the development of energy-efficient cryogenic devices. Until now, nearly all superconducting spintronic devices have relied on direct interfaces between superconductors and ferromagnets, since it was believed that an insulating barrier would decouple spin and charge transport. This assumption, however, appears to be invalid when a thin spin- and orbit-filtering barrier couples an epitaxial ferromagnet and a superconductor. Symmetry filtering plays a crucial role in enhancing giant tunneling magnetoresistance by selectively allowing specific electronic states to tunnel through the barrier. Such a mechanism is key for high-performance spintronic devices like magnetic random access memory, magnetic sensors or spin light-emitting diodes. On the other hand, spin–orbit coupling (SOC) is a central mechanism for perpendicular magnetic anisotropy in spintronics. Recently, it has become clear that SOC is crucial in mediating the interactions in heterostructures combining superconductors and ferromagnets, otherwise antagonistic materials where exotic interfacial quantum phenomena have been discovered over the last decade. Building on recent advances in studies of various V/MgO/Fe(100)-based systems, this manuscript provides a comprehensive review of superconducting spintronics driven by electron symmetry filtering and interfacial SOC. It emphasizes the critical role of a crystalline MgO barrier in selectively transmitting specific electronic states between V(100) and Fe(100). The manuscript also highlights how interfacial SOC enables symmetry mixing, allowing for the interaction between ferromagnetic and superconducting orderings through MgO(100). This mutual interaction, mediated by interfacial SOC, facilitates the conversion of spin-singlet to spin-triplet Cooper pairs. The work provides key insights into designing SOC-based superconductor-ferromagnet hybrid structures for advanced superconducting spintronic functionalities.

Index Terms- superconducting spintronics, spin orbit coupling, spin symmetry filtering, spin supercurrent, shot noise

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