Superconductor/Altermagnet Heterostructures: Bridging Unconventional Magnetism and Superconductivity

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Spintronics exploits the spin degree of freedom of electrons to store and process information and has already enabled technologies such as spin-transfer torque magnetic memories (STT-MRAM). However, conventional spintronic devices based on ferromagnets suffer from stray magnetic fields that limit further miniaturization and device stability. Antiferromagnets, with their vanishing net magnetization, offer an appealing alternative, yet the absence of spin splitting in their electronic structure has long restricted their use in spin-dependent transport phenomena.

Altermagnets represent a recently established class of magnetic materials that combines compensated antiparallel magnetic order with strong spin polarization in the electronic band structure [1,2]. Unlike conventional antiferromagnets, altermagnets exhibit a momentum-dependent spin splitting that arises from their distinct crystal and spin symmetries, even in the absence of spin–orbit coupling. This non-relativistic spin splitting can reach energy scales of electronvolts, comparable to those in ferromagnets, while maintaining vanishing net magnetization. This unique combination makes altermagnets promising candidates for spintronic applications, including spin-polarized transport, spin–charge conversion, magnetoresistance, and spin-transfer torque effects [3,4]. The altermagnetic properties of materials such as MnTe and CrSb have recently been demonstrated experimentally [5,6].

Beyond conventional spintronics, altermagnets offer exciting opportunities for superconducting spintronics, where the interplay between superconducting pairing correlations and spin-polarized electronic states enables novel functionalities. Their combination of strong, anisotropic spin splitting and vanishing net magnetization provides a promising route to coupling superconductivity and magnetism without the stray-field limitations of ferromagnetic systems. While superconducting/altermagnetic heterostructures remain largely unexplored experimentally, recent theoretical studies predict a rich variety of unconventional proximity effects. These include the generation of long-range spin-triplet Cooper pairs [7], spin-selective Andreev reflection [8], and unconventional Josephson coupling governed by the momentum-dependent spin splitting [9]. In this talk, the successful growth of such an altermagnet/superconductor heterostructure is presented.

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