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Exploring anisotropic phases and spin transport in perovskite heterostructures: Insights into 3d/5d interfaces for antiferromagnetic spintronics

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ABSTRACT

Transition metal oxides (TMOs) demonstrate a broad spectrum of properties encompassing electronic correlations, anisotropic transport, magnetism, and optical behavior. The anisotropy arises from both intrinsic crystal symmetry and extrinsic factors like epitaxial strain and structural asymmetry at TMO interfaces. Weiss and Neel's work has elucidated anisotropic magnetic behavior in antiferromagnetic (AFM) materials. AFM TMOs exhibit unique magnetotransport behavior, including weak antilocalization (WAL) and anisotropic magnetoresistance (AMR). Understanding the magnetic structure and band topology in AFM perovskites and their interfaces enables the tailored design of materials for spintronics and energy conversion. In few interfaces lacking inversion symmetry, Rashba spin–orbit coupling (SOC) induces WAL, a quantum correction in conductivity in a two-dimensional electronic system. Electron accumulation and charge transfer across 3d, 5d transition metal-based perovskite interfaces affect WAL and AMR, as observed in 3d/3d and 3d/5d AFM heterostructures, respectively. Advancements in spintronics rely on exploring spin-dependent transport anisotropy. This review focuses on various scattering mechanisms, categorized as extrinsic and intrinsic, in anisotropic transport, particularly in 3d/5d AFM superlattices. The WAL scattering mechanism depends on both intrinsic factors related to Rashba SOC-induced band topology and extrinsic sources like spin impurities and lattice ions. Moreover, the investigation into AMR mechanisms involves the application of impurity-based extrinsic scattering models, which are aligned with the Rashba and Dresselhauss models on Fermi surfaces. This exploration specifically targets the interface of two-band insulators, exemplified by $LaAlO_3/SrTiO_3$ and $LaVO_3/KTaO_3$. Furthermore, this model achieves comprehensive coverage, extending its applicability to 3d/5d AFM heterostructures like $LaMnO_3/SrIrO_3$ and $CaMnO_3/CaIrO_3$. Additionally, the intrinsic scattering mechanism tied to Berry phase effects related to band topology is studied, focusing on the $CaMnO_3/CaIrO_3$ superlattice. Despite manipulation challenges stemming from reduced stray fields, AFM materials show potential in interface physics and applications within the realm of spintronics.

I. INTRODUCTION

In recent years, the pursuit of innovative materials and architectures for next-generation spintronics devices has led to a burgeoning interest in antiferromagnetic (AFM) spintronics.[1–6] This emerging field harnesses the unique properties of AFM materials to manipulate spin currents, promising enhanced performance, reduced energy consumption, and increased functionality in spin-based applications.[2–4] One of the noteworthy features of AFM spintronics is its potential for achieving exceptionally high writing speeds, operating within the picosecond timescale. This accelerated performance is made feasible by the terahertz (THz) scale AFM resonance, a frequency that surpasses ferromagnetic resonance frequencies by three orders of magnitude (typically in the gigahertz range).[5,6] The study of anisotropy is