Electronic spin structure of quasi-two-dimensional systems with combined spin–orbit and exchange interactions

A.V. Tarasov [1,2], * A. G. Rybkin [2], A.S. Frolov [1,3], D.A. Estyunin [1,2], A.M. Shikin [2]
[1] Center for Advanced Mesoscience and Nanotechnology, Moscow Institute of Physics and Technology, Dolgoprudny, Russia
[2] St. Petersburg State University, Saint Petersburg, Russia
[3] Chemical Department, Lomonosov Moscow State University, 119991 Moscow, Russia
*email: tarasov.phys@yandex.ru

Key words: topological insulators, graphene, spin-orbit coupling, rashba effect, spintronics

Quasi-two-dimensional materials are a promising platform for spintronics and quantum computing. Graphene and topological insulators (TIs) are of particular interest due to their unique interplay of electronic structure, magnetism, and the Rashba effect. The combination of strong spin-orbit coupling (SOC) and magnetism can induce non-trivial topological phases and complex spin textures, enabling control over electronic and spin properties.

In TIs, SOC plays a decisive role in band inversion, which gives rise to bulk topological order and topological surface states (TSS). At the same time, Rashba states may emerge on the surface, as observed in $Mn_{1-x}A_xBi_2Te_4$ (A = Ge, Sn, Pb), where magnetic and non-magnetic TI properties are combined. Our results show that hybridization of Te-pz and Bi-pz orbitals with those of the substituting element leads to distinct topological phases and possible topological phase transitions. Ab initio calculations and ARPES confirm the presence of Rashba-like surface states (RSS), which evolve systematically with increasing A concentration. RSS shift towards the Fermi level, enhancing their interaction with TSS, and at higher concentrations penetrate deeper into the crystal with a strong orbital contribution from the dopant [1]. These findings establish $Mn_{1-x}A_xBi_2Te_4$ as a universal platform for studying RSS–TSS interaction and controlled topological transitions.

Unlike TIs, free-standing graphene is non-magnetic and exhibits weak SOC. However, interaction with heavy and magnetic substrates can strongly modify its properties, providing conditions for spin current generation and quantum Hall effects. In the Gr/Au/Co(0001) heterostructure, the substrate induces strong SOC and ferrimagnetic ordering in graphene, accompanied by A/B sublattice asymmetry and the opening of a 30–40 meV gap at the K-point, confirmed by STM/STS and DFT calculations [2]. Moreover, ARPES and spin-ARPES reveal spin-polarized states with conical dispersion near the Γ-point, localized around triangular dislocations from Au–Co lattice mismatch. These states exhibit magnetic dichroism and remain stable under graphene coverage and gold clusters, underlining the technological relevance of this system. Therefore, Gr/Au/Co(0001) represents a promising platform for realizing the quantum anomalous Hall effect and for spintronic applications.

This work was supported by St. Petersburg State University (project 125022702939-2).

Bibliography

[1] A.V. Tarasov, et al. Phys. Rev. B 111, 165115 (2025)
[2] A. G. Rybkin et al., Phys. Rev. Lett. 129, 226401 (2022)