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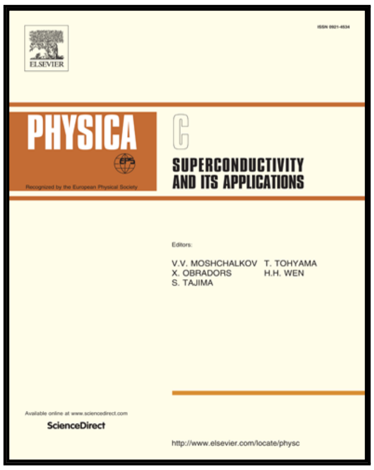

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Quantum transport in new two-dimensional heterostructures: thin films of topological insulators, phosphorene

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Abstract

The unusual features of the charge and spin transport characteristics are investigated in new two-dimensional heterostructures. Intraband specular Andreev reflection is realized in a topological insulator thin film normal/superconducting junction in the presence of a gate electric field. Perfect specular electron-hole conversion is shown for different excitation energy values in a wide experimentally available range of the electric field and also for all angles of incidence when the excitation energy has a particular value. It is further demonstrated that the transmission probabilities of the incoming electrons from different spin subbands to the monolayer phosphorene ferromagnetic/normal/ferromagnetic (F/N/F) hybrid structure have different behavior with the angle of incidence and perfect transmission occurs at defined angles of incidence to the proposed structure with different length of the N region, and different alignments of magnetization vectors. Moreover, the sign change of the spin-current density is demonstrated by tuning the chemical potential and exchange field of the F region.

Keywords: Charge transport, Topological insulator thin film, Andreev reflection, Phosphorene, Magnetotransport.

1. Introduction

Transmisssion of low energy electrons through a normal metallic-superconducting (N/S) junction is realized via Andreev reflection (AR), through which an electron with an excitation energy ε and spin polarization σ, upon hitting the N/S interface is retro reflected as a hole with the same energy but opposite spin direction $-\sigma$ [1]. This peculiar scattering process provides a conversion of the dissipative electrical current in N region into a dissipationless supercurrent and results in a finite conductance of a N/S junction at bias voltages below the superconducting gap [2]. Recent studies have pointed out that novel interesting phenomena arise when N/S proximity structures are realized in atomically thin two-dimensional crystals [3, 4, 5]. Beenakker showed the appearance of specular AR in undoped graphene, which is absent in ordinary metal-superconductor interfaces [3]. Also, Lv and co-workers found the possibility of the intraband specular AR in a corresponding structure with two-dimensional (2D) semiconductor in the presence of a strong Rashba spin-orbit coupling [6].

On the other hand, three layered structures consisting of two magnetic layers with general magnetization directions, separated by a conducting-nonmagnetic layer are well-known systems that exploit spin transfer torque effects [7, 8]. When applying a charge current perpendicular to the layers, one of the magnetic layers, referred to as the pinned layer, acts as a spin polarizer. When the spin-polarized electrons reach the second layer, referred to as the free layer, they accumulate at the interface and thereby exert a torque onto the free layer. The spin transfer can also be understood in analogy with Andreev scattering at N/S interfaces [9]. This spin-transfer torque effect can cause magnetization switching for sufficiently large currents without the need for an external field and provides a unique opportunity to create fast-switching spin-transfer torque magnetic random access memories (STT-MRAM) [10].

In this paper, the unusual features of the charge and spin transport are studied in new 2D materials such as thin films of topological insulators (TI) and monolayer black phosphorus. At first, it is focused on the theoretical investigation of the electronic transport properties in a TI thin film hybrid structure. Recently, low-dimensional structures of three-dimensional (3D) TIs can be routinely fabricated into ultrathin films [11, 12] with the advantage that they have minimum bulk contribution. The ultra TI thin film is interesting when its thickness becomes comparable to the penetration depth of the helical surface states into the bulk, and top and bottom surfaces thus starts to hybridize [12]. The possibility of intraband specular AR is revealed in such a N/S structure in presence of a gate electric field. It is demonstrated that the tunability of the potential difference between the top and bottom surfaces of the TI thin film, $2U$, leads to the perfect specular AR not only for the near-normally incident electron with different excitation energies but also for all angles of incidence to the proposed structure with $\varepsilon = \Delta_S$, small coupling parameter ω and large value of U. These results show the advantages of the proposed structure over the graphene- and 2DEG-based structures [3, 6], where the specular AR with unit efficiency only occurs for the normal incidence and the case of the $\varepsilon = \Delta_S$ in presence of the strong Rashba spin-orbit interaction, respectively.

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