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Electron transport in a monolayer graphene modulated by ferromagnetic–Schottky metal stripes

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ABSTRACT

We investigate the electron transport in a monolayer graphene modulated by the magnetic–electric barriers, which can be experimentally realized by depositing a ferromagnetic metal (FM) stripe and a Schottky metal (SM) stripe on top of the monolayer graphene. It is shown that the electron transmission and the conductance are strongly dependent not only on the incident energy and the incident angle of carriers, but also on the applied voltage and the width of the SM stripe as well as the strength of the magnetic field. These can be very helpful for exploring the tunneling mechanism of magnetically and electrically modulated graphene.

1. Introduction

In the latest years, due to the experimental realization of the graphene (a single atomic layer of graphite) [1,2] and the potential nano-electronic applications of the graphene-based devices [3–5], the electron transmission in the graphene-based structures is widely investigated [6–8] both experimentally and theoretically. In graphene, the low-energy electron transmits ballistically and could be described by the massless Dirac equation [9]. As a result of this, many interesting phenomena absent in conventional materials are found in graphene, including minimal conductivity [10] and the

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half-integer quantum Hall effect [11]. Moreover, another one is the perfect transmission through wide and high electrostatic barriers for normal incidence, which is named as the Klein tunneling [12].

Recently, the transport properties of massless Dirac fermions have received extraordinary interest in graphene-based structures modulated by the single or double barriers [13–15], and many unconventional-physical phenomena are obtained in these structures. Furthermore, extensive studies [16–18] have shown that the inhomogeneous magnetic fields on the nanometer scale can easily control the massless two-dimensional Dirac electrons, providing another method to the manipulation of electrons in graphene. Therefore, numerous theoretical and experimental studies [19–23] have been directed towards the transport properties for Dirac electrons through more complex multiple barrier configurations and magnetic superlattices in monolayer and bilayer graphene.

In this paper, we investigate the transport properties of massless Dirac fermions in a monolayer graphene modulated by a FM stripe and a SM stripe [24–26] deposited on top of the graphene. The applied voltages on both FM and SM stripes provide two electrostatic barriers [27]. The dependence of the electron transmission and the conductance on the applied voltage, the width of the SM stripe, the strength of the magnetic field and the incident energy as well as the incident angle of carriers is in detail investigated. This study may lead to potential applications in various graphene-based electronic devices.

2. Theoretical method and formulas

We consider the motion of massless Dirac electrons in the graphene (x,y) plane as sketched in Fig. 1, where B denotes the strength of the magnetic field, symbols U_1 and U_2 are the heights of the electrostatic barriers, L_2 gives the distance between the FM stripe and the SM stripe, L_1 and L_3 denote the widths of the FM stripe and the SM stripe, respectively. For simplicity, the magnetic field provided by the FM stripe and the electrostatic potential which are both assumed to be homogeneous in the y direction and vary only along the x axis can be approximated [28,29] as a delta function and the rectangular electrical barrier, respectively. In the vicinity of the Dirac point, the low-energy excitations can be described by the following Dirac equation:

$$[v_F\sigma(\mathbf{p}+e\mathbf{A})+U(x)\sigma_0]\psi=E\psi, \quad (1)$$

where $v_F\approx 10^6$ m/s is the Fermi velocity of graphene, $\sigma=(\sigma_x,\sigma_y)$ is the Pauli matrix, $\mathbf{p}=(p_x,p_y)$ is the momentum of the electron, $\mathbf{A}=[0,A_y(x),0]$ is the magnetic vector potential given in the Landau gauge, and σ_0 is the 2×2 unit matrix. For convenience, we introduce the dimensionless units, the magnetic length $l_{B_0}=\sqrt{\hbar/eB_0}=81.1$ nm and the energy $E_0=\hbar v_F/l_{B_0}=7.0$ meV with $B_0=0.1$ T as some typical

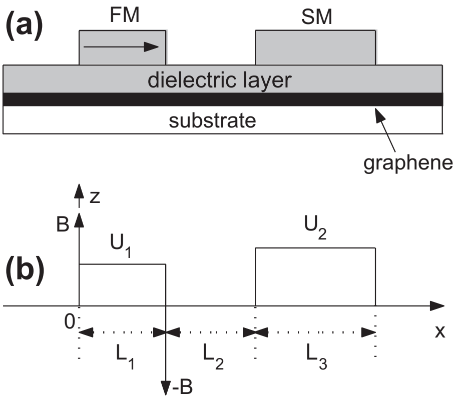

Fig. 1. (a) Schematic illustration of the considered monolayer graphene modulated by one FM stripe and one SM stripe. The applied voltages on both FM and SM stripes provide two electrostatic barriers. (b) Simplified profiles of the magnetic field $B(x)$ and the electrostatic potentials U_1 and U_2.