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Spin-dependent shot noise in magnetic graphene superlattice

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ABSTRACT

We study the spin-dependent shot noise properties in magnetic graphene superlattice with Rashba spin–orbit interaction (RSOI). The magnetic field generated by N parallel ferromagnets (FM) deposited on a dielectric layer. We consider two types of magnetic profiles: the FM stripes with magnetization parallel (P) or antiparallel (AP) perpendicular to the graphene. It is found that the shot noise of a spin state can be efficiently controlled by the number of barrier, RSOI strength and magnetic field. In the first case the Fano factor shows a peak with value approximately $F = 1/3$ for the both spin-up and spin-down electrons at new Dirac-like point. The position of the new Dirac point is robust against the magnetic field and RSOI. In the second case the Fano factor increases by increasing the number of barriers, and plateau of the Fano factor is formed. The results indicate that there is a strong relationship between spin-dependent shot noise and the magnitude of the spin polarization.

1. Introduction

Graphene, two-dimensional material tightly packed into a monolayer honeycomb lattice, was first synthesized by Novoselov et al. [1,2]. In low energy regime, the charge carriers in graphene are described by the massless Dirac-like equation. As a result, graphene presents many unique electronic and transport properties [3–9]. Spin-dependent transport in semiconductors is one of the most active field in Spintronics. On the other hand, graphene is an attractive candidate for spin-based devices. Furthermore, the spin relaxation time and length in graphene is long due to very small intrinsic spin–orbit coupling (SOC) [10,11] and absence of hyperfine coupling [12]. In graphene Rashba spin–orbit interaction (RSOI) can have different origins, including the interaction of carbon atoms with the substrate electric field, buckling, ad-atoms or presence of a perpendicular external electric field [13]. The strength of the RSOI λ_R is less than 1 meV at typical value of an external electric field (50 V/300 nm) [10]. However, Varykhalov et al. were reported that the interaction of Au atoms between the graphene and Ni substrate can enhance the λ_R to 13 meV [14]. Recently, Marchenko et al. also observed a large RSO splitting ($\sim$100 meV) in a monolayer graphene [15].

The transmission probability in a finite superlattice was firstly studied by Esaki and Tsu [16]. Since the experimental realization of graphene superlattices [17–19], the transport properties and electronic bandgap structures in graphene superlattice were extensively investigated [20–28]. To circumvent the Klein tunneling effect, it was suggested that a magnetic barrier can effectively block Klein tunneling and achieve confinement for massless Dirac fermions in graphene [29]. The graphene magnetic barrier structures can be realized by depositing ferromagnetic stripes on the graphene layer [30,31]. In recent years, many theoretical works focus on the transport properties through magnetic barriers in graphene [32–37].

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Shot noise is a powerful tool to obtain information of transmission in mesoscopic systems that is not available through the standard conductance measurements [38,39]. Shot noise originates from the fluctuation in the electrical signal due to the discreteness of electron charges. The shot noise characterized by the Fano factor F, which is defined as the ratio of the noise power to mean current [40]. Recently, some papers reported the shot noise in semiconductor heterostructures and graphene based nano-structures both theoretically and experimentally [7,8,41–57]. Also, experimental results of shot noise measurement in graphene structures are in good agreement with the theoretical predication [7,58]. Tworzydlo et al. predicted that for wide and short graphene sample the factor F has a maximum value of 1/3 at the Dirac point, which is 1/3 of Poissonian value [42]. Zhu and Guo investigated shot noise in the graphene double barrier structures and found that the shot noise with the Fano factor equal to 1/3 occurs at the Dirac point [43]. Cheianov and Falko studied the unusual Fano factor in p–n graphene junctions. In the previous paper [55], we investigated shot noise in graphene superlattice without taking into account the spin states of the electron. In this work, we focus on the spin-dependent shot noise properties in magnetic graphene superlattice in the presence of Rashba spin–orbit interaction (RSOI), which to the best of our knowledge was not already been reported. Our calculations are based on the transfer-matrix method. The effect of the number of barriers and RSOI on the Fano factor is taken into account. We also examine relationship between spin-dependent Fano factor and the magnitude of the spin polarization. The rest of the paper is organized as follows. In the next section, we introduce our method and formalism. In Section 3, our numerical results for the RSOI effect on the spin-dependent tunneling and the Fano factor are presented. Finally, a brief summary and conclusion are given in Section 4.

2. Model and theory

In this paper, we consider two types of systems. In the first and the second cases ferromagnetic (FM) stripes with magnetization parallel (P) or antiparallel (AP) perpendicular to the graphene are deposited on top of the dielectric layer, respectively. In our model the barrier region with the RSOI is separated by a normal graphene (NG) in which there is no RSOI interaction. The schematic of the structure is shown in Fig. 1. Using the single electron picture; the charge carriers in our model are expressed by the following Hamiltonian:

$$\widehat{H} = \widehat{H}_0 + \widehat{H}_{RSO} + V(x)\widehat{I}, \tag{1}$$

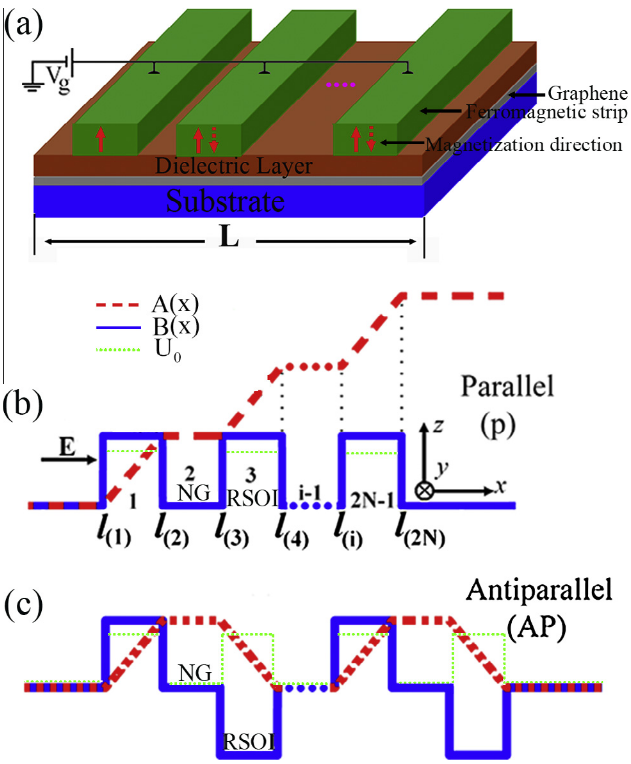

Fig. 1. (a) Schematic illustration of the monolayer graphene covered by a thin insulating layer, parallel FM stripes are deposited on top of the insulating layer. The gate voltage V_g applied on the FM stripes controls the height of electrostatic barrier U_0. The FM stripes have magnetization parallel (P) or antiparallel (AP) to the z axis. (b) Magnetic field profile $B(x)$ and corresponding vector potential $A(x)$ when FM stripes have magnetization parallel to the z axis. (c) $B(x)$ and $A(x)$ when FM stripes have magnetization antiparallel to the z axis.