SHOT NOISE IN NORMAL-FERROMAGNETIC-NORMAL GRAPHENE

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In this paper the transport properties of normal-ferromagnetic-normal graphene structures are studied by the Landauer Büttiker approach. The properties of spin chiral ferromagnetic layer are investigated when exchange energy exceeds the Fermi energy. To this end, the conductance as well as the shot noise are calculated. The Pauli exclusion principle that acts only on the carriers with the same spin, reduces the shot noise from its Schottky value. The effects of shot noise on the carriers with opposite spins in a ferromagnetic graphene are considered and it is observed that in this case the shot noise is lower than that of non-graphene systems since the quasiparticles with opposite spins are correlated due to chirality. In this way we report a new source of fluctuations in spin chiral materials.

Keywords: Graphene; Pauli exclusion principle; spin-chiral; shot-noise.

1. Introduction

Graphene, the strictly two-dimensional allotrope of carbon atoms,\(^1\) has attracted tremendous attention in the scientific community in light of both its novel physical properties and its spectacular applications in microelectronics and spintronics. Graphene naturally is a zero gap semiconductor\(^2,3\) that has the potential to be a superconductor, a quantum dot or a ferromagnet. It has been experimentally verified that ferromagnetic and superconducting graphene is realized with proximity effects.\(^4\) It has also been theoretically demonstrated that the induced exchange field in graphene is around 5 meV.\(^5\)

The peculiar physical properties of graphene are due to the fact that its low-lying excitations are chiral massless Dirac fermions, behaving quite differently from the usual quasiparticles in traditional semiconductors. In light of chiral nature of quasiparticles in graphene, they are able to tunnel through high and wide electrostatic barriers. This phenomenon is referred to as the Klein tunneling.\(^6,7\) Interestingly enough, it has been reported\(^8,9\) that ferromagnetic graphene with exchange field higher than Fermi energy could be realized as a spin chiral material. This means that carriers with opposite spins of different types have opposite chiralities.
We are inspired by the insightful papers in Refs. 8 and 9 to explore this interesting material driven from graphene. To shed more light on this material we study transport properties including conductance and non-equilibrium temporal fluctuations of the current (shot noise). Several theoretical studies of shot noise in ferromagnetic-normal systems, in two-terminal and multi-terminal systems, have been reported.11–13 Shot noise has turned out to be very useful in study of graphene.14–16

Shot noise is associated with the corpuscular nature of electric charge and its suppression from the Poissonian value emanates from Pauli exclusion principle and probabilistic scattering at the junctions.17–19 The suppressed shot noise in case of non-interacting quasiparticles in the two-terminal diffusive non-graphene system has been found to be 1/320,21 which is accidentally equal to that of a graphene system for high aspect ratio (W/L, where W is the width and L the length of the system) at the Dirac point.22,23 Surprisingly, other sources of fluctuation in current has been reported.12,24,25

Pauli exclusion principle which acts only on electrons with the same spins, lowers normalized shot noise (Fano factor) when transport is due to uncorrelated stochastic processes. We will see that in spin chiral materials, chirality between carriers with opposite spin correlates them and reduces the Fano factor further. It is the purpose of the present study to show this new source of fluctuation by considering the shot noise of charge carriers with opposite spin in a spin chiral material.

2. The Model

In what follows we calculate the conductance and current fluctuations of the all-graphene normal-ferromagnet-normal (NFN) junction, using scattering approach of Landauer and Büttiker.26,27 The system under consideration is similar to that presented in Ref. 9 and is illustrated in Fig. 1.

The behavior of low energy carriers moving in a monolayer graphene sheet adequately is described by the 2D Dirac Hamiltonian:

\[
H = v_f p \cdot \tau \otimes \sigma_0 - \tau_0 \otimes \hbar \sigma_z - E_f \tau_0 \otimes \sigma_0
\]

where \(v_f\) is the effective fermi velocity, \(\tau\) denotes pseudo-spin matrix and \(\sigma_0\) is real spin matrix.

As a preliminary step, we begin by calculating the conductance of the stripe of ferromagnetic graphene attached to normal graphene electrodes. For calculating the conductance, the transmission probabilities are required in right region. The sum of incoming and reflected wave functions in left region (for incoming carriers in one subband) reads:

\[
\psi_L = a \begin{pmatrix}
 e^{-i\alpha/2} \\
 e^{i\alpha/2} \\
 0 \\
 0
\end{pmatrix} e^{ikx} + r_{22}^+ a \begin{pmatrix}
 e^{i\alpha/2} \\
 -e^{-i\alpha/2} \\
 0 \\
 0
\end{pmatrix} e^{-ikx} + r_{22}^+ a \begin{pmatrix}
 0 \\
 0 \\
 e^{i\alpha/2} \\
 -e^{-i\alpha/2}
\end{pmatrix} e^{-ikx}.
\]