On the Role of Rashba Spin-Orbit Coupling in Graphene Nanoribbons

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I. INTRODUCTION

Since the discovery of graphene, this two dimensional material with a honeycomb lattice has been the subject of extensive research. Owing to its long electronic mean free path, high intrinsic carrier mobility, long spin coherence time, and high breakdown current densities, graphene has been envisioned as a suitable material for future electronic applications [1], [2], [3].

Recent theoretical studies predicts the conversion of graphene into a spin Hall insulator, in which a spin current flows perpendicular to an electric field. This phenomenon, caused by intrinsic spin-orbit coupling (SO), leads to counter-propagating spin-filtered edge states in a graphene strip [4], [5]. The flow and manipulation of spin currents has extensive applications in spintronics. However, weak spin-orbit coupling in graphene and fabrication challenges of perfect graphene nanoribbons (GNRs) hinder the experimental feasibility of SO-based spin currents.

Another well-known approach to creating a spin current emerges when an SO-dependent scattering potential interacts with electrons. This scattering potential can be caused by a strong electric field [6]. The effective spin-orbit coupling generated is called the Rashba spin-orbit (RSO) interaction. Recent experiments predict that strong RSO can be realized in graphene, which is controllable by a giant electric field [7]. The compelling theoretical and experimental evidence of observable RSO in graphene [7], [8], along with the indispensable role of RSO in the field of spintronics, clarifies the necessity to investigate this effect in graphene nanoribbons.

II. MODEL AND DISCUSSION

In this work, the influence of RSO on electronic transport of graphene nanoribbons has been investigated. The results are focused on armchair edge nanoribbons because of their substantial energy gaps, which makes them suitable for switching applications. Since the electrons in π bonds are responsible for electronic trans-port in graphene, a first-nearest-neighbor tight-binding method is used to model the band structure of graphene nanoribbons. The hopping parameter between the nearest neighbors, t, is assumed to be -2.7eV. The Hamiltonian for RSO can be written as [9]:

$$\sum_{<ij>} iC_i^\dagger(\vec{U}_{ij}.\sigma)C_j + \text{H.c.} \tag{1}$$

σ stands for the Pauli matrices and $\vec{U}_{ij}$ is given by:

$$\vec{U}_{ij} = -\frac{\lambda_R}{2}\hat{z} \times \vec{\delta}_{ij} \quad . \tag{2}$$

λ_R represents the RSO strength. $\vec{\delta}_{ij}$ is the vector between two atomic sites, i and j.

Figure 1 shows the probability amplitude of the first wave function with a positive energy for an AGNR in three different cases. Figure 1a is in absence of RSO and Figures 1b and 1c are in presence of RSO for spin up and spin down respectively. As can be seen, in the absence of RSO, electrons are most likely to be found in the middle of the ribbon. However, when RSO is applied, it breaks the degeneracy between opposite spins. The interaction couples spin up and spin down, leading to a spatial separation of the two spins along the width and consequently a spin current.

III. CONCLUSION

In summary, we studied RSO in graphene nanoribbons within a tight binding model. We showed that the states are expected to be strongly affected by the presence of the RSO interaction. RSO produces localized spin-dependent states along the edge and spin polarization. This finding opens the possibility of making field-effect spin devices that could manipulate simultaneously both the spin and charge of carriers.
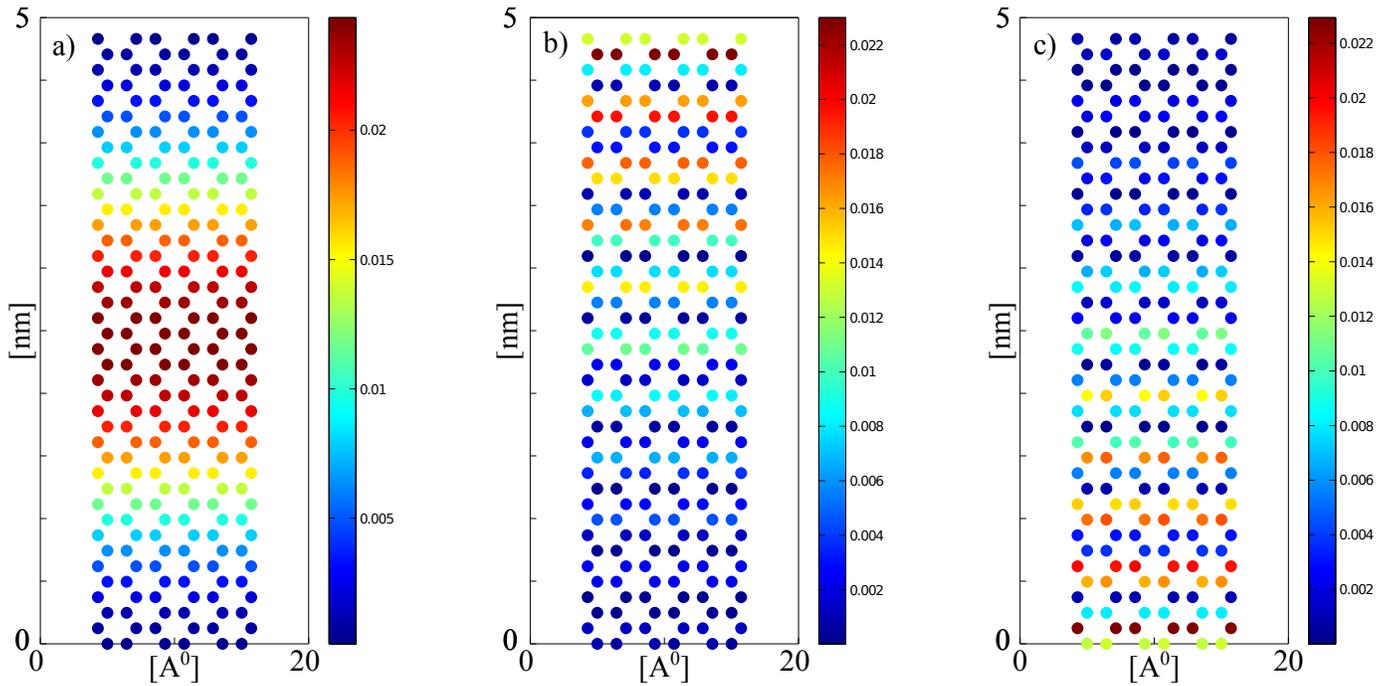
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Fig. 1: Probability amplitude of the first wave function with a positive energy in an AGNR with $N = 40$ (N is the number of carbon along the edge). Panel (a) is in absence of RSO; (b) and (c) are in presence of RSO, for spin up and spin, down respectively. $k = 0$ and $\lambda_R = 0.2t$.

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