Physica E 77 (2016) 23–28

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Shot noise fluctuations in disordered graphene nanoribbons near the Dirac point

Víctor A. Gopar

Departamento de Física Teórica and BIFI, Universidad de Zaragoza, Pedro Cerbuna 12, E-50009 Zaragoza, Spain

HIGHLIGHTS

- Effects of disorder and edge terminations on the shot noise power fluctuations in graphene nanoribbons are studied.
- Zigzag and armchair nanoribbons have different shot noise statistics.
- The presence of Anderson and anomalous localizations in zigzag and armchair nanoribbons, respectively, leads to different statistical properties of the shot noise power.

ARTICLE INFO

Article history:
Received 23 June 2015
Received in revised form
25 September 2015
Accepted 29 October 2015
Available online 30 October 2015

Keywords:
Shot noise power
Graphene disordered nanoribbons
Electron localization

ABSTRACT

Random fluctuations of the shot-noise power in disordered graphene nanoribbons are studied. In particular, we calculate the distribution of the shot noise of nanoribbons with zigzag and armchair edge terminations. We show that the shot noise statistics is different for each type of these two graphene structures, which is a consequence of the presence of different electron localizations: while in zigzag nanoribbons electronic edge states are Anderson localized, in armchair nanoribbons edge states are absent, but electrons are anomalously localized. Our analytical results are verified by tight binding numerical simulations with random hopping elements, i.e., off diagonal disorder, which preserves the symmetry of the graphene sublattices.

1. Introduction

It is widely recognized that time dependent current fluctuations due to the discreteness of the electrical charges—shot noise power—provide further physical information of an electronic system than other transport quantities such as the conductance. For instance, the shot noise takes into account the Pauli principle and thus, it can reveal electron correlations. Markus Büttiker and collaborators recognized the importance of the shot noise for the understanding of the problem of quantum electron transport and made major contributions to this topic.

The shot-noise power can be studied by using a scattering approach to quantum transport. Within this framework, Büttiker found that the shot-noise power spectrum P, in the zero frequency limit and zero temperature, can be written as [1,2]

$$P = 2eVG_0 \sum_{n=1}^{N} T_n(1 - T_n), \tag{1}$$

where $G_0 (= 2e^2/h)$ is the conductance quantum, V the applied voltage, while the T_n's are the transmission eigenvalues of the Hermitian matrix $tt^\dagger$, with t being the $N \times N$ transmission matrix. If there were no correlations among electrons, the shot noise is given by the Poisson value $P_P = 2eVG_0 \sum_n T_n$. The shot noise power has been extensively studied both experimentally and theoretically in small electronic devices such as quantum wires and quantum dots, in which quantum coherence is preserved. The literature on this topic is very extensive, we thus refer the reader to the review articles Refs. [3,4].

In general, electron correlations reduce the shot noise respect to the case of fully uncorrelated electrons. The Fano factor F defined by the ratio $F = \langle P\rangle/\langle P_P\rangle$, where the brackets indicate energy or ensemble average, measures that suppression of the shot noise. Using random matrix theory to quantum transport, it has been predicted that the Fano factor takes the value 1/3 for disordered quantum wires in the diffusive regime limit [5,6], while for ballistic chaotic quantum dots $F = 1/4$, in the limit of large number of channels supported by the leads attached to the dots [7,8]. Thus, universal values of the shot noise suppression have been predicted for both transport regimes.

With respect to graphene, several electronic properties have

E-mail address: gopar@unizar.es

http://dx.doi.org/10.1016/j.physe.2015.10.032
1386-9477/

been intensively studied since its discovery in 2004, and the shot noise is not an exception (for a review, see [9,10]). For pristine graphene structures whose lengths are shorter than their widths, a 1/3 shot-noise suppression has been predicted, at the Dirac point [11]. This suppression value coincides with the Fano factor value for disordered normal-metal wires in the diffusive regime.

Although pristine graphene structures show many interesting electronic properties, in real graphene-based devices those properties may be affected by the presence of disorder [10,12–20]. Different sources of disorder such as ripples, vacancies, adatoms, or distortions of the lattice produced by interactions with the substrate [21,22] can be found in graphene, even suspended graphene structures are not free of defects [23,24].

Effects of the presence of disorder on the shot noise in graphene sheets have been experimentally and theoretically investigated [10,25–29]. It has been found that the Fano factor is affected by the strength of the disorder, as well as the length-to-width ratio of the graphene sample. Most of those studies, however, have been concentrated on wide geometries and models of disorder that break the chiral symmetry of the graphene sublattices.

Here, we are interested in the properties of the shot noise at the Dirac point in finite disordered graphene samples, i.e., disordered nanoribbons, in which the edge terminations as well as the symmetry of the graphene sublattices play a crucial role in the electronic properties. We thus investigate the random fluctuations of the shot noise power for the two different edge terminations: zigzag and armchair, Fig. 1. For both terminations, we consider the so-called off-diagonal disorder (random hopping connecting the two graphene sublattices) in order to preserve the chiral symmetry of the graphene sublattices. This kind of short-range disorder might model distortions like ripples in the graphene lattice. Actually, experimental evidence of short range disorder in graphene has been observed [30–32]. Therefore, here we are interested in studying the effects of the nanoribbon edge terminations and the presence of disorder on the statistical properties of the shot noise power.

The most interesting properties of graphene are found at low energies, i.e., near the Dirac point where a linear dispersion relation holds and an analogy with relativistic massless particles has attracted much attention. Also, the lattice symmetry of graphene or chiral symmetry, resulting in a symmetric energy spectrum around the Fermi energy plays an important role in the description of the electronic properties; hence, we are interested in calculating statistical properties of the shot noise near the Dirac point. We recall that in clean graphene nanoribbons the band structure is determined by the edge termination and the width of the nanoribbons. Actually, armchair nanoribbons show either semiconducting or metallic band structures depending on their width; in particular, the band structure is metallic when $n = 3m - 1$, with n being the number of carbon atoms in the transverse direction and m an integer (in this work $m=4$); for other values of the armchair nanoribbon width, a band gap is open at the Fermi energy and no transport occurs near that energy. Thus, here we will only consider disordered nanoribbons with attached perfect leads whose band structure is metallic (Fig. 1). In the next section we introduce a statistical model to describe the random fluctuations of the shot noise power, Eq. (1).

2. Statistical model

The statistical properties of the shot noise power in disordered graphene nanoribbons can be analyzed through the statistical properties of the transmission eigenvalues T_n, as we can see from Eq. (1). A well established theoretical framework to study the transmission statistics of disordered systems is the one-parameter scaling approach to localization [33] and random matrix theory [34]. Our statistical analysis of the shot noise is based on that scaling approach to Anderson localization and a recent extension to the case of anomalous localization [35,36]. In general, the manner in which electrons are localized determines the statistical properties of quantum transport. Therefore, the statistics of the transmission, or conductance, for standard (Anderson) and

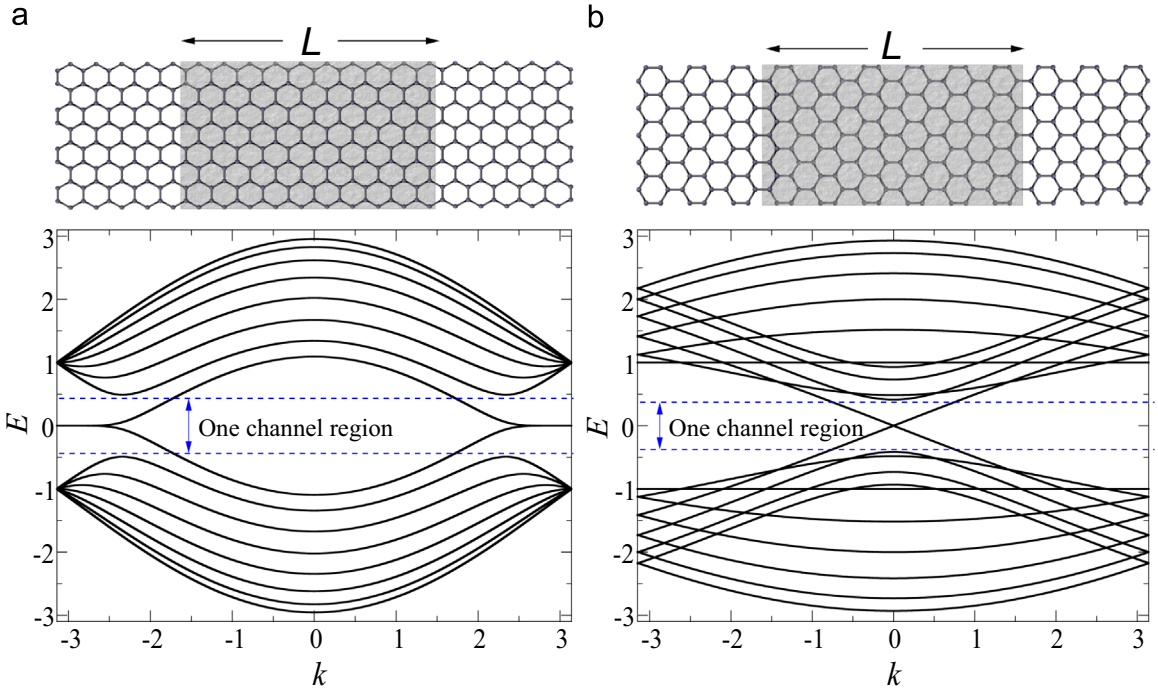

Fig. 1. Disordered graphene nanoribbons (shaded areas) of length L with zigzag (a) and armchair (b) edges with perfect graphene leads (non-shaded areas) attached. The width W of the nanoribbons has been fixed: $W = 11a/\sqrt{3}$ and $5a$ for zigzag and armchair nanoribbons (with a being the lattice constant $a \simeq 2.46$ Å), respectively. With those widths, the attached perfect leads have gapless metallic band structures.