Symmetry-dependent conductance behavior in graphene-based double-dot structures

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Introduction

Some of us have recently found and investigated an interesting effect, consisting in a strong symmetry-dependence of the conductance of two quantum dots in series separated by a tunnel barrier and connected to the external leads through input and output constrictions [1]. The conductance reaches a maximum value, which can counterintuitively be much larger that that in the absence of the constrictions, when the system is completely symmetric, i.e. the two constrictions are in positions symmetric with respect to the barrier, and no magnetic field is present. Any symmetry-breaking action makes the conductance decrease significantly. This effect derives from the constructive interference of many transport paths that in a symmetric structure share the same length and thus the same phase. The effect was studied in a semiconductor heterostructure and an application for sensors of position or magnetic field was suggested.

The fabrication of analogous sensors in graphene would be very attractive, because it would make possible to exploit specific properties of graphene, such as the high mobility at room temperature. However, transport in graphene has peculiar characteristics leading to a different behavior. For example, transport through a barrier in graphene exhibits Klein tunneling, which makes the barrier perfectly transparent in the case of normal incidence and derives from the relativistic-like behavior of electrons, or, equivalently, from the matching of the electron states outside the barrier with the hole states inside it.

Here we show the results of a study, in the ideal case without disorder, of double-dot structures defined in monolayer graphene, and we show that the mentioned symmetry-related effect does appear.

Method and results

We consider an idealized structure with the geometry and the potential landscape sketched in Fig. 1. We numerically study this structure solving, in the Fourier space, the Dirac envelope equation in each region with longitudinally constant potential, and then applying a recursive scattering matrix method.

We have studied several device configurations. For example, in Figs. 2 and 3 we show the results obtained considering a structure with two $2\ \mu\mathrm{m} \times 2\ \mu\mathrm{m}$ dots, with 400 nm wide constrictions and a 55 nm thick and 50 meV high tunnel barrier. In Figs. 4 and 5 we have instead considered $1\ \mu\mathrm{m} \times 1\ \mu\mathrm{m}$ dots, with 200 nm wide constrictions and a 30 nm thick and 50 meV high tunnel barrier. In Figs. 2 and 4 we report the conductance, as a function of the electron Fermi energy, of the barrier and of the cavity alone, and of the cavity with the barrier in the central and 10 nm shifted positions. In all of the considered cases we see that the presence of the cavity reduces the transmission of the structure with respect to the barrier alone, but the conductance remains clearly dependent, in a large range of energies, on the position of the tunnel barrier and thus on the symmetry in the structure. This is even clearer in Figs. 3 and 5, where we show, for a Fermi energy of 30 meV, the dependence of the conductance on the shift of the tunnel barrier with respect to the central position.

These results show that, at least in the absence of significant disorder, the dependence of the conductance on symmetry survives in graphene coupled dots.

References

[1] R. S. Whitney, P. Marconcini, M. Macucci, Phys. Rev. Lett. **102**, 186802 (2009).

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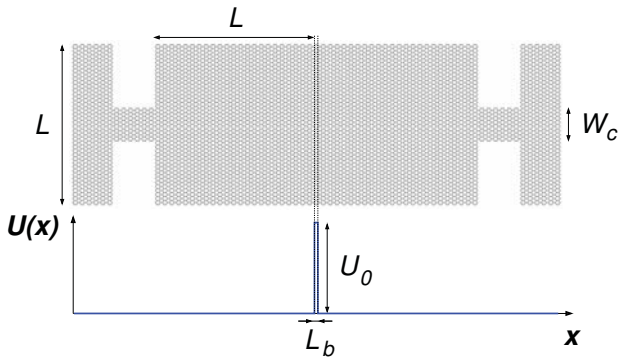

Fig. 1. Sketch of the considered graphene-based double-dot structure, and dependence of the potential energy U on the longitudinal position x.

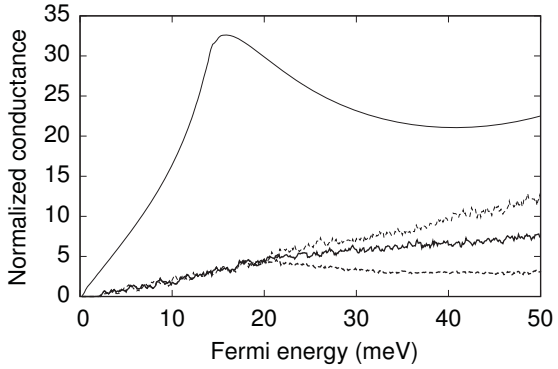

Fig. 2. Conductance (normalized with respect to the conductance quantum) as a function of the electron Fermi energy, for the barrier alone (thin solid curve), for the cavity alone (thin dashed curve), and for the cavity with the barrier in the center (thick solid curve) and in a 10 nm shifted position (thick dashed curve). These results have been obtained for a structure with (see Fig. 1) $L = 2$ μm, $W_c = 400$ nm, $L_b = 55$ nm and $U_0 = 50$ meV, with a transversal number of dimer lines in the two dots corresponding to a semiconductor armchair ribbon.

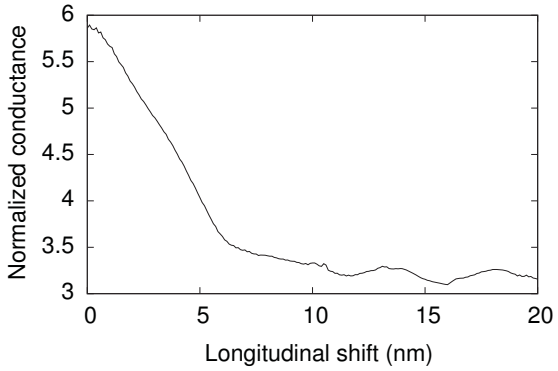

Fig. 3. Normalized conductance of the structure considered in Fig. 2 as a function of the shift of the tunnel barrier from the central position, for a Fermi energy of 30 meV.

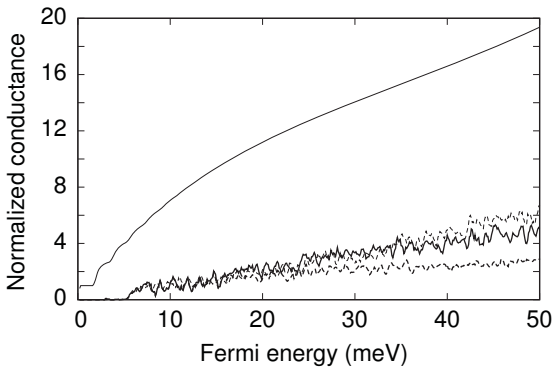

Fig. 4. Normalized conductance as a function of the electron Fermi energy, for the barrier alone (thin solid curve), for the cavity alone (thin dashed curve), and for the cavity with the barrier in the center (thick solid curve) and in a 10 nm shifted position (thick dashed curve). These results have been obtained for a structure with (see Fig. 1) $L = 1$ μm, $W_c = 200$ nm, $L_b = 30$ nm and $U_0 = 50$ meV, with a transversal number of dimer lines in the two dots corresponding to a metallic armchair ribbon.

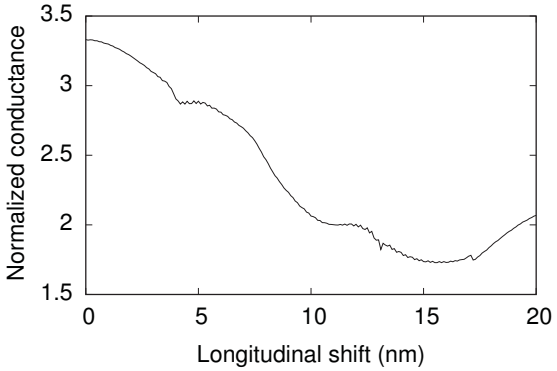

Fig. 5. Normalized conductance of the structure considered in Fig. 4 as a function of the shift of the tunnel barrier from the central position, for a Fermi energy of 30 meV.