TOWARD A GRAPHENE-BASED QUANTUM INTERFERENCE DEVICE

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Graphene is a promising candidate for replacing semiconductors as basic material for the design of new nanodevices due to its truly two-dimensional geometry as well as large carrier mobility [1]. However, confining and controlling charge carriers in graphene remains a complicated task because of its very special tunneling properties [2]. Therefore, a significant amount of efforts has been focused on graphene-based nanodevices that could enhance carrier confinement, such as p-n junctions [3, 4] and superlattices [5, 6, 7].

Interference effects of coherent electron transport through graphene nanorings open an alternative way to control quantum transport without relying so much on the confinement. These interference effects were already observed as Aharonov-Bohm conductance oscillations in ring-shaped devices etched in graphene when a perpendicular magnetic field was applied [8]. In this contribution we introduce a new graphene interference device (GID) in which electron transport is controlled without applying a magnetic field. We demonstrate that charge carrier transport can be tuned instead by applying a lateral gate voltage across a graphene nanoring. We show that in this case the relative phase of the electron wave function in the two arms can also be varied, leading to a constructive or destructive interference at the output and, therefore, to current modulation.

It is well known that the type of the nanoribbon edges (zigzag or armchair) determine its electronic structure [1]. To avoid the impact of energy structure changes on the transport, we used the ring geometry with 60^o turns, so that the type of edges remains the same for the whole sample. The results depicted in Fig. 1 correspond to samples having lead widths of 20 (left panel) and 21 (right panel) unit cells (4.9 and 5.1 nm contact widths respectively). The nearest-neighbor tight-binding Hamiltonian formalism and the quantum transmission boundary method [9] were employed to calculate the transmission coefficient and current-voltage characteristics of the device for different source-drain, back-gate and lateral gate voltages.

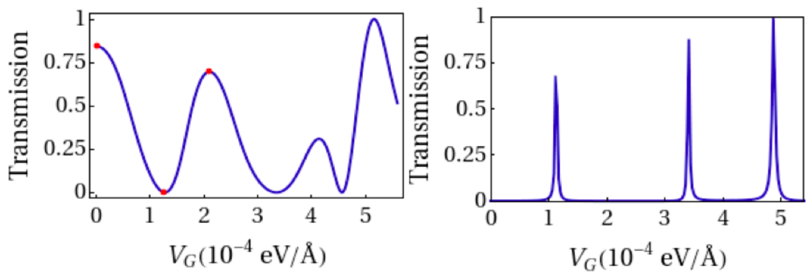

Figure 1: Transmission coefficient for two different nanorings at a given energy E=0.15 eV as a function of the applied lateral electric field. Left panel all nanoribbons comprising the ring have widths of 20 unit cells (corresponding to a Dirac-like dispersion relation), right panel sample with 21 unit cells wide branches (the parabolic dispersion case). The resonance-like behavior in the former case and the interference-like one in the latter case can be seen.

For energies close to the Fermi energy (which can be controlled by the back-gate), two types of behavior were obtained. Nanorings with armchair edges having an intrinsic energy gap manifested wide transmission bands (see Fig. 1, left panel), while resonance-like behavior characterized by very sharp peaks in the transmission were observed in the remaining cases (see Fig. 1, right panel). Such narrow transmission peaks can easily be affected by disorder or other perturbations resulting in low reliability of the device. Contrary to that, the former case is much more promising. We demonstrate that the modulation of the wide transmission bands shown in Fig. 1 are due to the interference effects. Figure 2 displays density plots of the electron wave functions in the considered GID calculated for three lateral gate voltages corresponding to maxima/minima of the transmission (marked with red dots in the left panel of Fig. 1). For an electron incident from the left, a clear constructive interference at the output (at the right extreme of the device) can be seen for the voltages corresponding to transmission maxima while the destructive interference pattern is observed for the case of zero transmission resulting in a vanishing current. We argue therefore that the device operates as a quantum interference device with high on/off ratio.

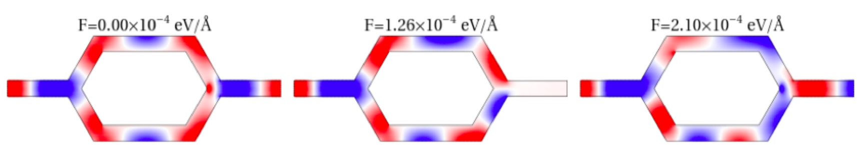

Figure 2: Density plot of the real part of the electron wave function for three lateral gate voltages (corresponding to red points in the left plot of Fig. 1). For the sake of clarity, only a regular sublattice of atoms (around 25% of the total number of atoms) is plotted. Interference effects due to different number of nodes/antinodes of the wave function in the two branches can clearly be seen at the output (right end of the nanoring).

References

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