Adiabatic quantum pumping in graphene with magnetic barriers

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Most research of electronic transport in graphene is focused on stationary problems. A variety of new effects emerges when one considers non-stationary ones. An interesting phenomenon is a quantum pump effect, in which a periodic modulation of parameters of a quantum system produces a finite dc current through it even in the absence of an external bias [1]. Quantum pumping in graphene has recently attracted increasing attention of researchers [2-6]. The unusual electronic spectrum of graphene was demonstrated to have a significant impact on the effect. The potential use of a quantum pump effect in graphene-based spintronics was also discussed.

Motivated by possible applications of a quantum pump effect in graphene valleytronics we extend previous studies of quantum pumping in graphene by taking into consideration the valley degree of freedom of electrons. The system that we examine is a standard two terminal quantum pump device that is formed by a wide graphene strip with two electric barriers (produced by top metallic gates) whose heights can be periodically modulated in time and one stationary magnetic barrier (see Fig.1). The model employs the low-energy Dirac approximation and incorporates the possible existence of a finite band gap in graphene spectrum.

By using a δ-function approximation for a magnetic barrier profile, analytical expressions for bilinear total and valley pumping responses are derived within the scattering matrix approach [7]. These results are compared to numerical ones for a double δ-function, a square and a triple square magnetic barriers. We find that a finite magnetic field breaks the perfect Klein tunneling so that all propagating modes become sensitive to pumping. At the same time a magnetic barrier decreases the overall efficiency of a quantum pump. The joint use of a magnetic barrier and band gap engineering in graphene breaks the valley symmetry and gives a way to generate valley-polarized currents in graphene-based quantum pumps (see Fig.2). The parameters of a device can be adjusted such that a pure valley current is produced. A δ-function and a square magnetic barrier profiles, which are employed in our model are widely used for studying the electron transport through magnetic barriers and can be viewed as simplified approximations to those created experimentally by ferromagnetic strips. More realistic smooth profiles can be analyzed in the same framework.

The considered pump effect might be found useful in the field of graphene valleytronics, e. g., as a source of valley-polarized and pure valley currents. Experimentally they could be detected using, for example, the valley Hall effect [8].

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Figures

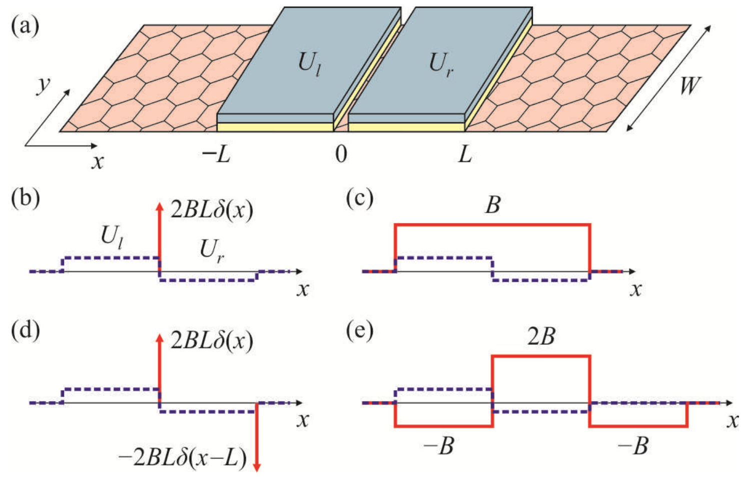

Figure 1: (a) A schematic structure of a proposed graphene device. The device is formed by a wide graphene ribbon with two square electric barriers and (b) a single δ-function magnetic barrier or (c) a square magnetic barrier or (d) a double δ-function magnetic barrier or (e) a triple square barrier.

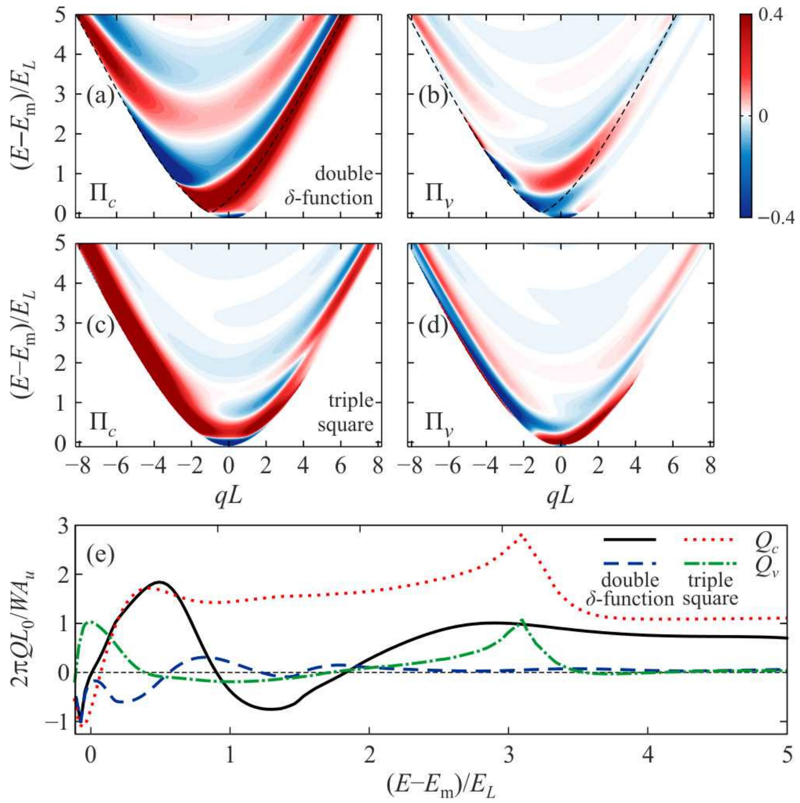

Figure 2: Contour plot of (a, c) the total and (b, d) the valley pumping responses for (a, b) the double δ-function magnetic barrier and (c, d) the triple square barrier in graphene with gapped spectrum as a function of the transverse canonical momentum q and the Fermi energy E. (e) The total (Q_c) and the valley (Q_v) pumped charges for a wide ribbon as a function of the Fermi energy E. Parameters: B=0.1 T; L=81.1 nm; E_L=6.6 meV; gap $\Delta=4E_L$. $E_m=E_L$ is the minimum value of the Fermi energy, above which the single (δ-function or square) magnetic barrier has a finite transparency.