Electron Transport through Field-induced Quantum Dots in Graphene

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Abstract

Graphene, a single atomic layer of graphite, and few-layer graphene sheets are one of the attractive two-dimensional conducting materials for a new stage of low dimensional physics. From the application point of view, the ballistic transport and high mobility in graphene make them possible candidates for future electronic quantum devices. Nanostructures on graphene sheets can be fabricated by carving out of the graphene sheets directly, and the spread two-dimensional sheet structure may open a door to realize the integrated quantum nanodevice system. However, carriers in graphene (massless Dirac fermions) cannot be confined by an electrostatic potential due to Klein tunneling [1]. Therefore, in most cases, the formation of graphene quantum-dot (QD) devices relies on the removal of unwanted areas of graphene by etching, thereby resulting in devices with a geometrical confinement [2–4]. We have also demonstrated double quantum-dot devices in triple-layer graphene, which exhibits single-electron transport of two lateral quantum dots coupled in series [5]. Coupled quantum-dot systems have been proposed for various applications as new logic and architectures, such as the quantum computation and the quantum cellular automata. Our results suggest an important step for the realization of the integrated quantum devices in graphene-based nanoelectronics. Although this top–down process enables precise control of graphene device structures on a submicron scale, the graphene-edge shape varies on a nanometer scale. Therefore, the transport properties of graphene QD or nanoribbon devices are often dominated by edge roughness and disorder [6, 7]. The performance of such devices is limited due to the detail of nanoconstriction structures. It is crucially important to develop other methods of creating graphene nanostructures and control the constrictions.

In this paper, we report an alternative device structure for achieving confinement, in which nanostructured graphene islands are perfectly isolated and metallic contacts are directly deposited onto them without constrictions. Such a configuration realizes direct contact with a nanostructured two-dimensional electron gas, and the confinement potential is induced by an electrostatic surface-potential formed by the metal/graphene junction [8]. With this device structure, we demonstrated that the Coulomb blockade evolves under a uniform magnetic field perpendicular to the graphene sheet. As discussed in Ref. [9-11], such a quantum confinement-deconfinement transition is corresponding to the transition between open-to-closed trajectories of Dirac particles in this type of device structure. All trajectories are open for a sufficiently weak magnetic field, which corresponds to a continuum spectrum. At high magnetic fields, closed orbits emerge that correspond to quasi-bound states and coexist with open trajectories. Moreover, the quasi-bound states should be consistent with the Bohr–Sommerfeld condition [9, 12] and lead to a discrete energy spectrum. In addition to that, tunnelling between open and closed trajectories leads to a finite resonance lifetime and QD formation. Our experimental results indicate that a quantum confinement–deconfinement transition is controlled by the magnetic field.

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