Quantum Transport in a Graphene Waveguide with Smooth Edge Terminations by Magnetic Vector Potential

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Graphene is a single atomic layer of carbon atoms of which low-lying excitation provides quasi-particles obeying the linear dispersion relation near the specific point in the momentum space called the Dirac points. For the freestanding graphene, the equality of two Dirac points leads to the valley degeneracy in addition to the spin, and the quasi-particles, which are named as the Dirac fermions, are massless and chiral. Because of these properties, the Klein tunneling has been an obstacle to using graphene for nanoelectronics[1]. In order to overcome it, magnetic vector potential structures induced by inhomogeneous magnetic fields can be candidates for a way of fabricating graphene-based electronic devices. Actually, the Dirac fermions are reflected and confined by the magnetic vector potential structures which do the role of potential structures in a real sense[2,3,4]. This magnetic confinement also allows us to overcome another difficulty in realizing graphene nanoelectronic devices such as graphene nanoribbons, which comes from the edge nature of graphene. There are typically two kinds of edge-terminations in graphene nanostructures, armchair and zigzag, and the electronic states are very sensitively dependent on the edge nature[5,6]. However, it is difficult to prepare nano-sized graphene samples having clean edges with the atomic-scaled precision.

In this study, we show that the waveguide is produced by applying the delta-function-like profile of magnetic field to the graphene sheet, and also investigate quantum transport in the magnetically modulated graphene waveguide in which the magnetically induced scattering potential is introduced at the center. This profile of magnetic field can be generated experimentally by using ferromagnetic gates onto the graphene layer as depicted in Fig. 1. The magnetically modulated graphene waveguide is treated as a quantum-wire with the finite conducting channels. Similar to the typical quantum-wire, the number of the conducting channels depends on the Fermi energy. In results, the well-localized current density is observed in the unmodified waveguide, and the conductance is calculated by the Landauer-Buttiker formula, which exhibits the stepwise increase as a function of energy. The interesting situation occurs when the waveguide is modified by introducing a magnetic potential barrier as a scattering center in the sense that the backscattering and foregoing Dirac fermions experience effectively different potential structures. While the foregoing Dirac fermions are still confined, the backscattering fermions are no longer confined because the effective potential depends on the longitudinal momentum, qx. For the modified waveguide, the conductance becomes oscillatory as shown in Fig. 2. The threshold energies to open the conducting channel are shifted because the scattering potential affects the transport properties. The results in the present study may provide the novel candidate for applications of graphene-based transport devices.

References

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Figures

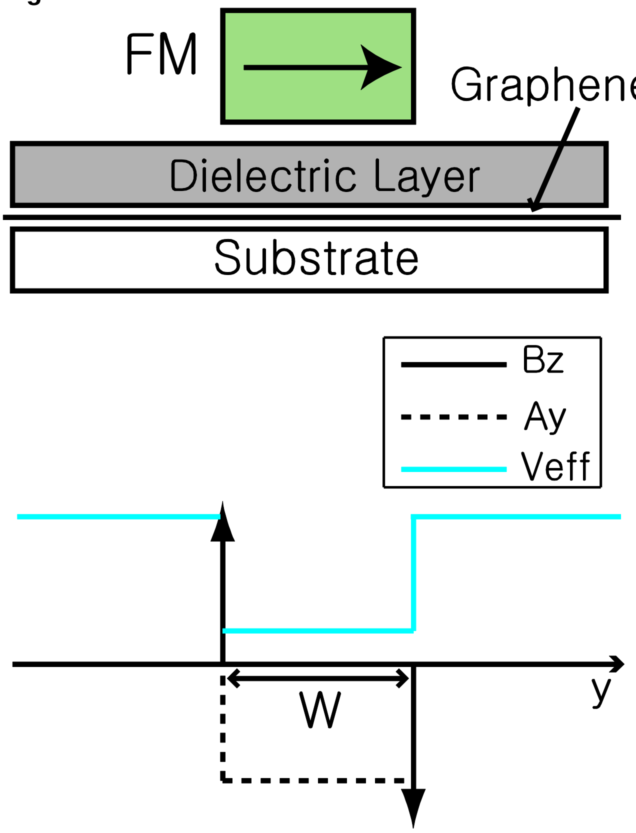

Figure 1
Schematic view of experimental setup and model.

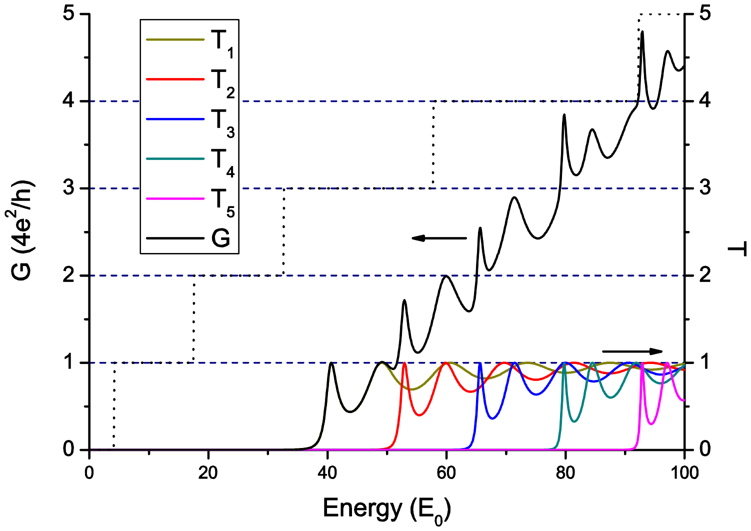

Figure 2
Conductance of the graphene waveguide and transmission probabilities for each channel.