Control of indirect magnetic coupling through a graphene nanostructure by electric field

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Graphene nanostructures, like nanoribbons, nanoflakes and quantum dots are expected to offer nontrivial magnetic properties [1]. What is even more interesting, these characteristics can be controlled with the help of the external electric field [2-5] or magnetic field [6]. This opens new possibilities for development of graphene-based spintronics and stimulates search for novel concepts of devices.

The paper presents a theoretical study of the indirect magnetic coupling mediated by charge carriers in a graphene nanostructure, being an ultrashort piece of a graphene nanoribbon with armchair edges. In the model, the magnetic planes are attached to zigzag terminations of the structure, while the gates parallel to the armchair edges serve as a source of in-plane external electric field. The electronic structure description is based on a tight binding model with Hubbard term [6,7] and electric field potential term. A fully non-perturbative determination of coupling energy is enabled by total energy calculations via self-consistent diagonalization of the system Hamiltionan in single-particle approximation.

In general, it is found that the zero-field or low-field coupling has antiferromagnetic character. For selected system sizes, it is demonstrated that the coupling magnitude and sign is highly sensitive to the electric field and that continuous switching to ferromagnetic coupling can be achieved when the field increases. Even stronger electric field causes another switching from ferro- to antiferromagnetic interaction. Such a phenomenon is of potential interest as it opens the door to controlling the sign and magnitude of the indirect exchange via electric field.

The dependence of the critical fields at which the indirect interaction reach the zero value is analysed as a function of size of the studied graphene nanostructures. Moreover, the influence of the exchange energy between spins in magnetic planes and spins of charge carriers in graphene on the predicted behaviour is investigated. It is found that the effect is robust against the mentioned factor. In addition, the importance of armchair edge deformation and Hubbard term is discussed.

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