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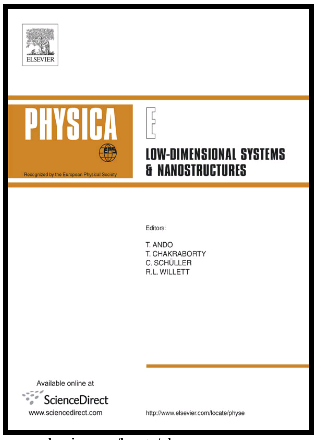

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Graphene based superconducting junctions as spin sources for spintronics

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We investigate spin-polarized transport in graphene-based ferromagnet-superconductor junctions within the Blonder-Tinkham-Klapwijk formalism by using spin-polarized Dirac-Bogoliubov-de-Gennes equations. We consider superconductor in spin-singlet s-wave pairing state and ferromagnet is modeled by an exchange field with energy of E_x. We have found that graphene-based junctions can be used to produce highly spin-polarized current in different situations. For example, if we design a junction with high E_x and E_F compared to order parameter of superconductor, then one can have a large spin-polarized current which is tunable in magnitude and sign by bias voltage and E_x. Therefore graphene-based superconducting junction can be used in spintronic devices in alternative to conventional junctions or half-metallic ferromagnets. Also, we have found that the calculated spin polarization can be used as a tool to distinguish specular Andreev reflection (SAR) from the conventional Andreev reflection (CAR) such that in the case of CAR, spin polarization in sub-gap region is completely negative which means that spin-down current is greater than spin-up current. When the SAR is dominated, the spin polarization is positive at all bias-voltages, which itself shows that spin-up current is greater than spin-down current.

Key words: A. Superconductors, D. Tunneling Phenomena

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I. INTRODUCTION

Graphene is a monoatomic layer of graphite with a honeycomb lattice structure. At six corner points of the two dimensional hexagonal Brillouin zone of graphene, the conduction and valence bands touch each other [1]. Experimental fabrication of graphene has aroused an enormous response in both experimental and theoretical scientists in a way that much works have been done on physical properties of graphene over the last years [2-6]. The electronic properties of graphene show several fascinating features, for example Dirac like energy dispersion as well as six-point Fermi surface, leads to zero effective mass at Fermi surface and energy-independent velocity. These features not only are in the interest of theoretical scientists, but graphene has a big potential for technological applications because of its unique combination of a very strong carbon-based structure and its unusual electronic properties.

One of the fascinating properties of graphene is about superconductivity. Although graphene does not show superconductivity intrinsically, superconductivity can be induced by inserting a superconducting electrode on the top of graphene [7-12]. So graphene will be a superconductor by proximity effect. Also, graphene can be a ferromagnetic metal in different ways. The presence of the defects on graphene is one way to observe ferromagnetism in graphene [13]. Another way is attributed to proximity-induced ferromagnetism in graphene which it is realized experimentally [14]. So, it is completely possible to have a segment of graphene as a ferromagnetic metal [15-17].

On the other hand, combining the magnetism and electronics has been produced an interesting research field known as spintronics, and it is based on the opportunity of magnetic materials to produce spin-polarized currents [18-22]. One goal in performance of any spintronic device, is the improve of spin polarization as high as it approaches 100%. This goal is achievable via the exploitation of half-metallic ferromagnets [18]. Superspintronic is a subfield of spintronics which is based on the idea of combining the magnetism and the useful properties of superconductors [22]. The order parameter of most superconductors is spin-singlet s-wave pairing state, which does not carry any net spin. Anyway, strong magnetic sources such as half-metallic ferromagnets in coexistence with superconductors can be used to produce high-spin polarization.

In Refs.(23,24), spin polarization for normal metal/superconductor junctions is studied theoretically. Both conventional s-wave and unconventional p-wave states are investigated, and it is shown that both junctions can produce high spin polarization in the case of high potential barrier. So, conventional normal metal-superconductor junctions can be used to produce highly spin-polarized currents that are tunable by bias voltages. Also, in Ref.(25), we have shown that a nano wire/d-wave superconductor junction can produce a high spin-polarized current in the case of low potential barrier. In fact, nano wires (one dimensional normal metals) and two dimensional normal metals in contact with superconductors in different situations can be used to generate high spin-polarized currents, which for more details one can refer to Refs.(23-25). Now, we want to investigate spin-polarized current on graphene superconductor junctions. Another question that arises in graphene-based superconducting junctions, is that how one can discriminate conventional Andreev reflection (CAR) from specular Andreev reflection (SAR) experimentally. Although both of CAR and SAR processes occur in graphene-based superconducting junctions, the discriminating process between them is an important issue from the physical point of view, because in the CAR process two electrons come from the same band while in the SAR process two participating electrons come from different bands. In the following one can see that spin-polarization can help to find the answer to the above question. Also, it should be noted that, in Refs. (33,34), an effective method is introduced to obtain a clear distinction