Spin-dependent transport in graphene-based nanostructures

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Abstract

The occurrence of large spin-coherence lengths [1] has spurred the interest in graphene as a material of choice for spintronic devices. In this contribution we show the occurrence of a spin-dependent transport and negative differential resistance (NDR) in quantum rings and superlattices based on armchair graphene nanoribbons. We consider nanoribbons with a set of ferromagnetic insulating stripes, like EuO, grown on top of it (Figure 1). The ferromagnets induce the exchange splitting of the electronic levels in the regions of the ribbon located just below the stripes. This results in a spin-dependent potential profile. One can choose the system geometry to produce a resonant mode close to the energy of the band edge for spin up electrons, paving the way for obtaining spin-dependent NDR.

Numerical simulations were carried out using the standard tight-binding model, taking into account up to the third nearest neighbor interaction and the hydrogenation of carbon atoms in the edge of the nanoribbon. We used the quantum transmission boundary method (see Refs. [2,3] for details) to obtain the spin-dependent transmission coefficient for a given energy and source-drain voltage. In the case of superlattices, results were compared to those obtained by the Dirac approach [4], valid at energies close to the Fermi level. Using the Landauer-Buttiker formalism we calculated the current-voltage characteristics.

We show that due to the exchange splitting induced by the magnetic ion of the ferromagnetic layer, the transmission coefficient in quantum rings, shown in left panel of Figure 1, is different for spin up and spin down electrons, giving rise to the polarization of the conductance and the electric current [3]. We demonstrated that both the current and its polarization can be controlled by a side-gate voltage. Predicted effects are shown to be robust under a moderate edge disorder and other fabrication imperfections, such as the asymmetry of the ring.

We found that the current-voltage curves show regions of well-defined NDR in the case of the superlattice shown in the right panel of Figure 1. The spin dependence of the transmission spectrum leads to different voltage intervals at which highly transmitting channels are open, which makes the NDR be spin-dependent too, as shown in Figure 2. We note that in a spintronic device the degree of freedom that carries information is the polarization of the current rather than its magnitude. We show that the current polarization is also a non-monotonic function of the source-drain voltage, suggesting that it can be used as resonant tunnel device. This opens a possibility to design a whole new class of true spintronic circuits such as spin oscillators, amplifiers and triggers

References

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Figures

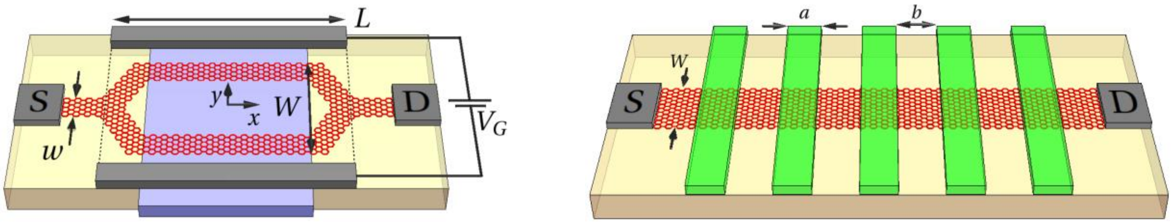

Figure 1. Schematic views of the nanodevices (quantum ring with side-gate voltage [3] at the left and superlattice [4] at the right), with ferromagnetic insulating stripes grown on top of them. The devices are connected to source (S) and drain (D).

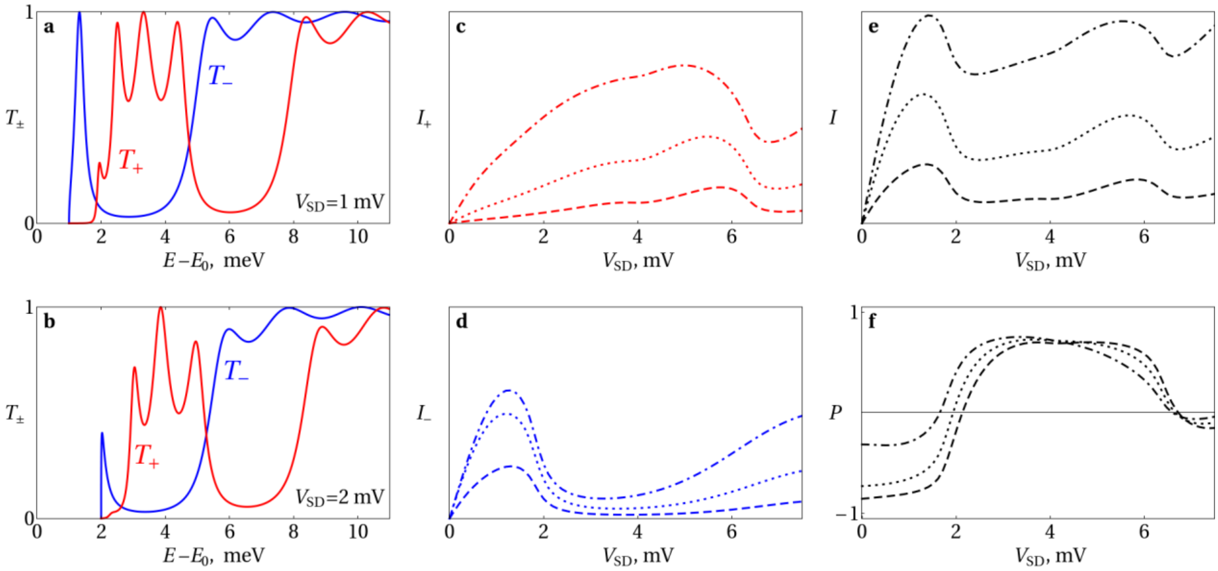

Figure 2. Panels a) and b) show the transmission bands in the superlattice for both spins at finite bias. Panels c) and d) display the spin-polarized currents $I_{\pm}$ as functions of the bias V_{SD}, for T = 4 K and different values of the chemical potential. Finally, panels e) and f) show the total current $I = I_{+}+I_{-}$ and the current polarization $P = (I_{+}+I_{-})/I$ for the same parameters. All the intensity plots use the same arbitrary scale.