Spin-dependent transport in graphene nanoribbons with a periodic array of ferromagnetic strips

J. Munárriz[1], C. Gaul[1,2], A. V. Malyshev[1], P. A. Orellana[3], C. A. Müller[4], and F. Domínguez-Adame[1]

[1]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain
[2]CEI Campus Moncloa, UCM-UPM, Madrid, Spain
[3]Departamento de Física, Universidad Católica del Norte, Casilla 1280, Antofagasta, Chile
[4]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore

j.munarriz@fis.ucm.es

Abstract

Since the pioneering work by Esaki in the late 1950s [1], negative differential resistance (NDR) has been the basis for the operation of many quantum devices. The underlying mechanism of NDR is related to the resonant tunneling of carriers through the device. When the chemical potentials of the leads match one of the resonant levels of the device, the current I increases dramatically. The resonant level depends on the applied source-drain voltage V_{SD}, which finally drives it out of resonance, such that the current decreases with a further increase of voltage. The resulting I-V characteristic in the NDR regime is not monotonic but N-shaped instead.

The unique properties of graphene, like its truly two-dimensional geometry as well as high carrier mobility and large mean free path, have attracted much attention for the design of novel quantum devices. Besides its remarkable properties for charge transport in nanostructures, the long spin-coherence length up to several microns makes graphene a material of choice for spintronic devices [2]. Ferromagnetic insulators deposited on graphene can induce ferromagnetic correlations of itinerant electrons. This opens the possibility of spin current generation.

In this work, we combine the aforementioned aspects, NDR and spin selectivity, in a graphene-based device. We consider a spin-dependent superlattice realized by ferromagnetic strips placed on top of an armchair GNR (see Fig. 1). Similar settings have been studied by Niu *et al* [3] – using bulk, gapless graphene instead of nanoribbons – and by Ferreira *et al* [4] – without taking into account spin dependence. We compute the spin-dependent transmissions, $T_{\pm}$, and I-V curves using a full tight binding (TBA) calculation, as well as the graphene Dirac Hamiltonian. The latter allows us to provide simple analytical expressions to determine the position of the resonant levels at $N = 2$, as well as the band structure as $N \to \infty$.

The energies of the transmission peaks and transmission bands strongly depend on the spin σ. First, we address the unbiased system, i.e., $V_{SD} = 0$. For the range of parameters chosen ($W = 9.84$ nm, $N = 5$, $d_a = 23.9$ nm, $d_b = 55.8$ nm, exchange splitting $h = 5$ meV; see Fig. 1), the overlap between transmission bands corresponding to different spins is small (see upper panel of Fig. 2). This is also revealed by the transmission polarization $P_T = (T_+ - T_-)/(T_+ + T_-)$, plotted in the lower panel of the figure, which presents abrupt shifts from -1 to 1, and vice versa. Then, we address the calculation of the current response of the device to a potential difference V_{SD} between source and drain, whose chemical potentials, $\mu_S = e\cdot V_{SD}+\mu$ and $\mu_D = \mu$ have the same offset μ from their corresponding band-gap centers. The well-known Landauer-Büttiker scattering formalism is used, setting the temperature T to 4 K, the results being plotted in Fig. 3. The spin-dependent shift of transmission bands permits the NDR to be found at different biases. For spin down $\sigma = -1$, the NDR slope can be quite steep. This is due to the fact that, at lower bias, the distortion of the transmission profiles with respect to the unbiased case $V_{SD} = 0$ is smaller, keeping a well defined peak at the energies of interest, surrounded by regions with vanishing transmission. At higher bias, the profiles are smoothed.

References

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Figures

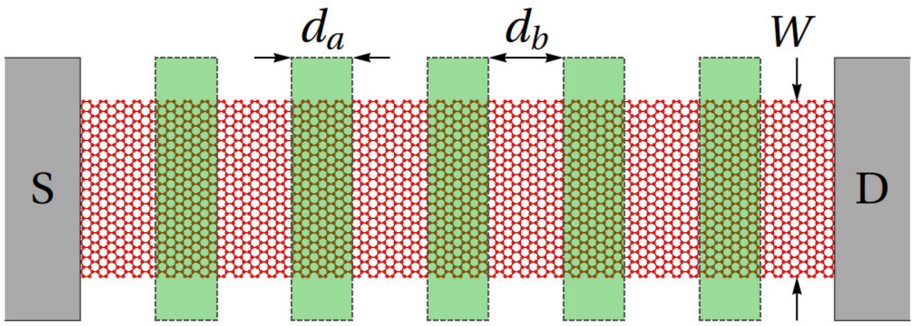

Figure 1: schematic view of a GNR, with $N = 5$ strips of a ferromagnetic insulator placed on top of it (shown as green bars). Source and drain terminals are denoted as S and D respectively.

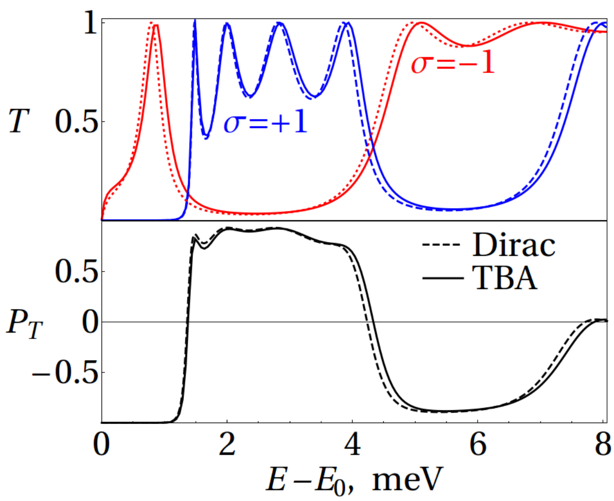

Figure 2: Upper panel shows the transmission coefficients as function of energy for $V_{SD} = 0$, obtained from the Dirac theory (dotted red and dashed blue lines show T_- and T_+, respectively), and from the tight-binding calculation (solid lines). Lower panel shows the degree of the transmission polarization $P_T=(T_+-T_-)/(T_++T_-)$.

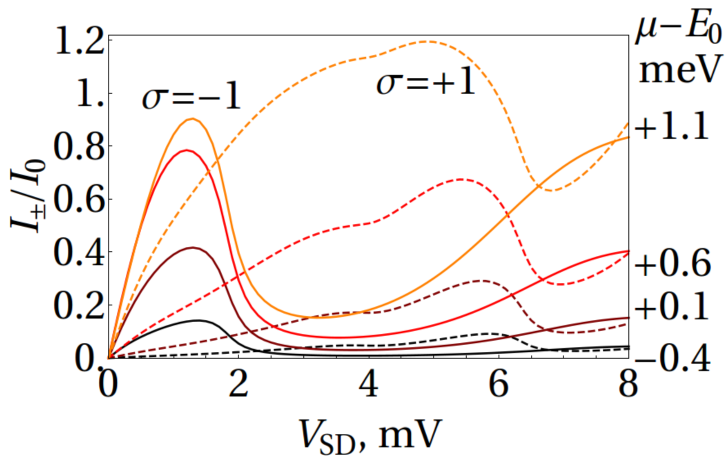

Figure 3: Currents I_+ (dashed) and I_- (solid) as function of V_{SD} for different values of the chemical potential μ in the leads.