Spin-dependent negative differential resistance in graphene superlattices

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Graphene is a novel material with a combination of many remarkable properties, in particular, large electron mobility and spin-coherence lengths of up to several microns [1-3]. These features have spurred the interest in graphene as a material of choice for spintronic devices which exploit both the charge and the spin degrees of freedom of charge carriers as the basis of their operation.

In this contribution, we predict a spin-dependent negative differential resistance (NDR) in superlattices based on armchair graphene nanoribbon (aGNR). The NDR has been reported previously for nonmagnetic gates in aGNR [4]. Here, we consider a nanoribbon with a set of ferromagnetic insulating stripes placed on top of it (see Fig. 1 for the schematics of the device with two stripes). The ferromagnets induce the exchange splitting of the electronic levels in the regions of the ribbon located just below the stripes, resulting in the formation of a superlattice. The superlattice is different for spin up and spin down electrons: it comprises potential barriers for the former and potential wells for the latter, which can lead to the spin-dependent current-voltage characteristics. Furthermore, one can choose the system geometry to produce a resonant mode close to the energy of the band edge for the spin up electrons, paving the way for obtaining spin-dependent NDR.

We considered samples with the following geometrical parameters: $W = 10$ nm, $w_b = 21$ nm and $w_h = 49$ nm (see Figure 1) and different numbers of ferromagnetic stripes *N=2,5,8* (larger samples are constructed by simple replication of the super unit cell). The simulations were carried out using the standard tight-binding model for π electrons, taking into account up to the third nearest neighbor interaction and the hydrogenation of carbon atoms in the edge of the ribbon [5,6]. Following Ref. [7], we used the quantum transmission boundary method [8] to obtain the wave function in the whole sample and the spin-dependent transmission coefficient for a given energy E and source-drain voltage V_{SD}. Fig. 2 shows the transmission spectra for V_{SD}=0. As the number of barriers is increased, the first transmission peak for spin-up electrons ($\sigma = +1$) turns into a miniband (see the left plot of Fig. 2), whereas for the spin down case ($\sigma = -1$) a new peak appears very close to the band edge (see the right plot of the figure).

Using the obtained transmission coefficients and the Landauer-Buttiker formalism we calculated the current–voltage characteristics shown in Fig. 3. The figure demonstrates that the *I-V* curves manifest regions of the NDR. The spin dependence of the the transmission spectrum leads to different voltage intervals at which highly transmitting channels are open, which makes the NDR be spin-dependent too. We believe that the latter constitutes an interesting new phenomenon and can be useful for applications.

References

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Figures

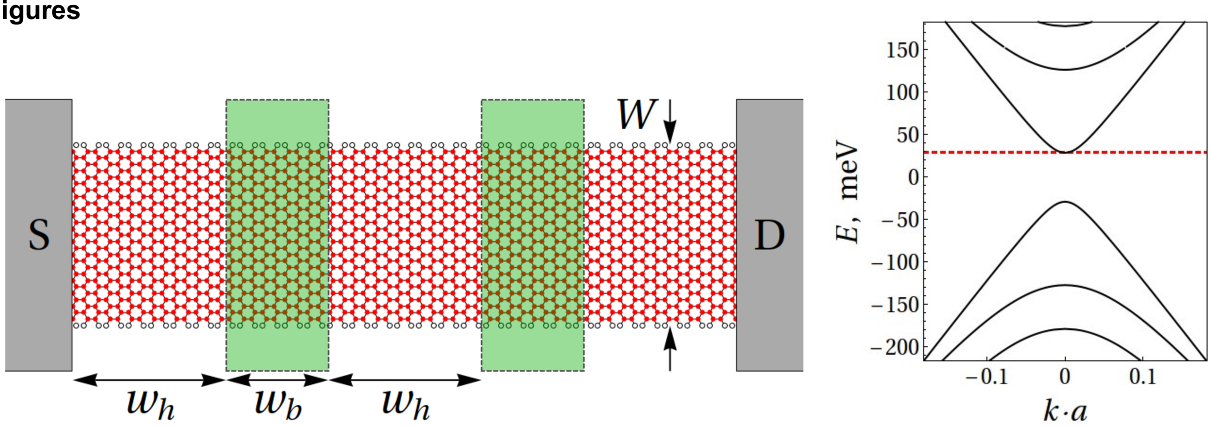

Figure 1: Schematic view of the proposed device (left panel) and the dispersion relation in an infinite aGNR with W = 10 nm *(right panel). The dashed line indicates the equilibrium Fermi level at* $\varepsilon_F = 28.5$ meV.

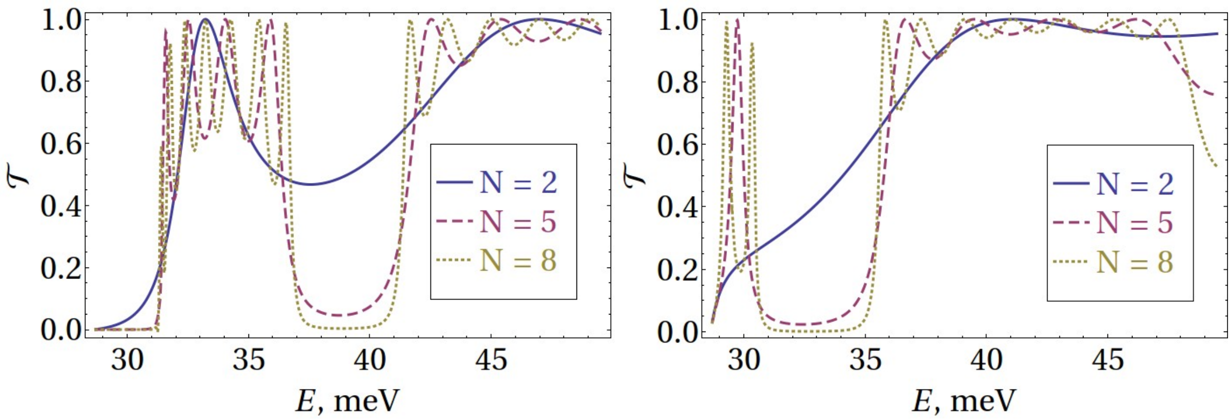

Figure 2: Transmission coefficient as a function of the energy for spin up (left plot) and spin down (right plot) states, for the superlattice described in the text and different number of barriers N*. As* N *increases, energy minibands appear, surrounded by regions with vanishing transmission probability.*

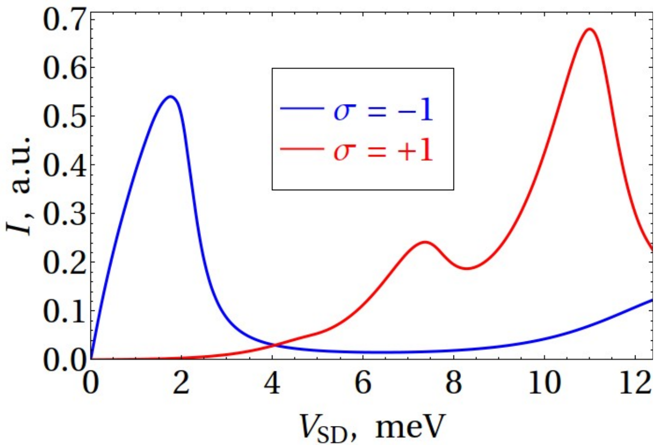

Figure 3: Current-voltage characteristics calculated for $N = 5$ *(at the temperature* $T = 4$ K*). Remarkably, the NDR is obtained for both spin states but at different source-drain voltages.*