Simulation of transport through a cavity defined in graphene with electrostatic lithography

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INTRODUCTION

We present numerical simulations that we have developed to reproduce and understand the results of the measurements which we have recently performed [1] on a graphene device (Fig. 1) in which a cavity-shaped potential, orthogonal to the transport direction (Fig. 2), has been induced with electrostatic lithography. The resistance of the sample has been measured both as a function of the backgate voltage V_{BG}, and of the position of a biased probe scanned at a fixed distance from the flake.

NUMERICAL METHOD

In order to explore a large range of possible potential landscapes and backgate voltage values, we have used a simplified numerical approach. Assuming to know the potential profile at a reference bias point, we have determined its variation as a function of the gate and probe voltages by analytically enforcing the self-consistent solution of two approximate relations [2]. The first one connects the local charge density to the graphene potential via the local density of states, which, for a slowly spatially-varying potential, has been expressed shifting the density of states by the local value of the potential. The second one, instead, relates the variations of the charge density, potential, and gate voltages through a simple capacitive model (Fig. 3). Under proper conditions, this set of relations is equivalent to a quadratic equation, which can be quickly solved for each point of the flake [2]. Once the potential profile was obtained, a transport calculation has been performed, obtaining the overall resistance with a recursive scattering matrix approach [3].

NUMERICAL RESULTS

The presence of a cavity-shaped potential leads to Fabry-Pérot resonances in the behavior of the resistance as a function of V_{BG} (Fig. 4). We have tried different potential profiles at the reference bias point, in order to find the best agreement with the experimental data for the set of voltages V_{BG} at which the resonance peaks appear (Fig. 5). The best fit has been achieved for a Lorentzian shaped cavity with a width of about 200 nm. We have then performed a numerical simulation of a scanning probe spectroscopy experiment, computing the resistance of the device as a function of the position of a biased probe. A plot of such resistance as a function of the probe position is reported in Fig. 6. The measured resistance maps are well reproduced if we assume the presence of disorder in the potential, such that the cavity is split into multiple subcavities in parallel (Fig. 2). The presence of the biased probe, altering the potential in the subcavity under it, shifts the value of V_{BG} for which the Fabry-Pérot resonances take place in that subcavity and thus gives rise to the circular features observed in the scanning probe maps. The charge accumulation at the edges of the flake introduces further oscillations in the behavior of the resistance as a function of V_{BG}, with a different periodicity due to the stronger capacitive coupling between the graphene and the gate (Fig. 4).

REFERENCES

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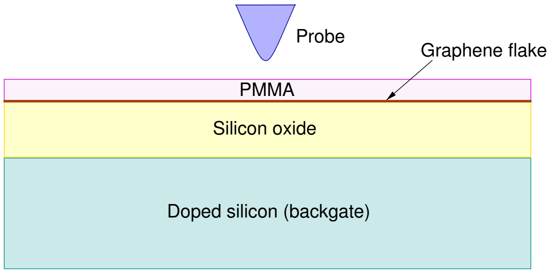

Fig. 1. Sketch of the simulated device.

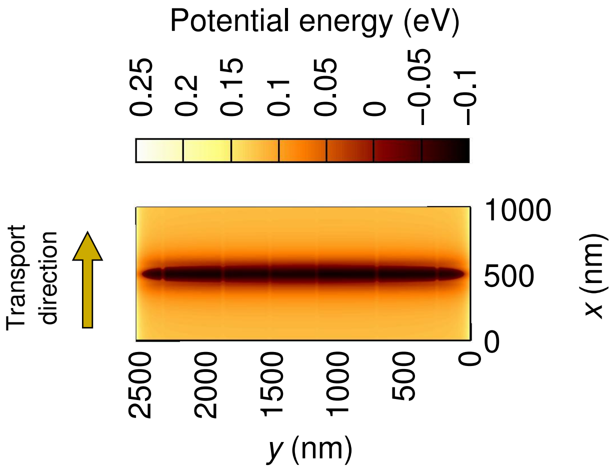

Fig. 2. Potential profile in the graphene flake, consisting of a cavity divided by low longitudinal walls into multiple subcavities in parallel.

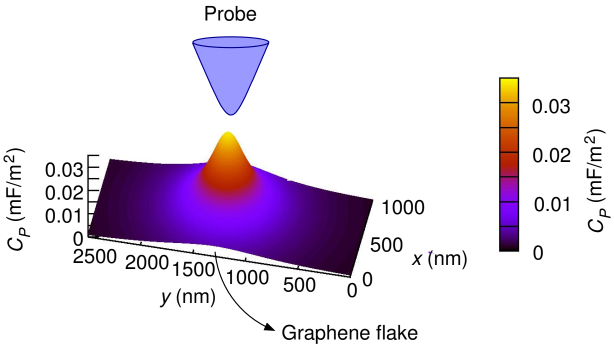

Fig. 3. The electrostatic coupling between the probe and each point of the graphene flake is modeled by means of a spatially-varying capacitance.

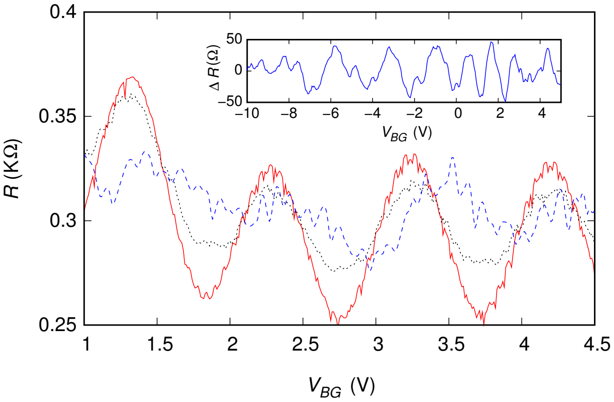

Fig. 4. Computed behavior of the resistance as a function of V_{BG} for a single Lorentzian cavity (red solid curve) and for multiple subcavities in parallel without (black dotted curve) and with (blue dashed curve) charge accumulation at the edges. The inset reports the experimental results, in terms of the resistance variation ΔR due to the cavity.

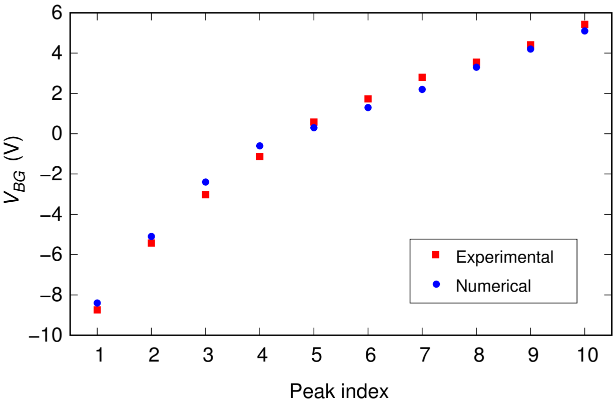

Fig. 5. Values of V_{BG} for which the Fabry-Pérot resonances appear, reported as a function of the peak index (the experimental and numerical results are compared).

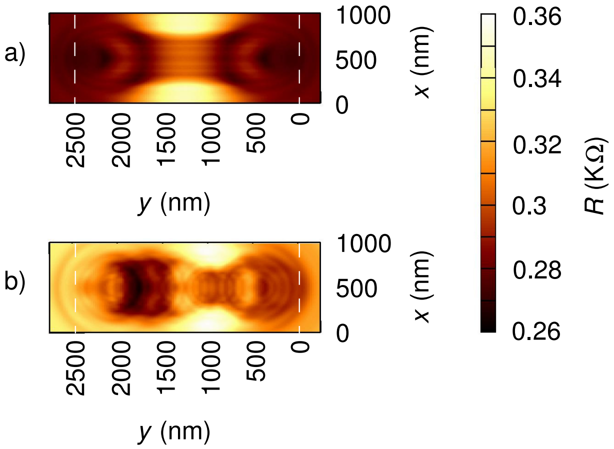

Fig. 6. Scanning probe resistance maps computed (a) for a single Lorentzian cavity; (b) for a cavity divided into multiple subcavities in parallel.