Geometrical effects on the viscous electron flow in graphene

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Electron-electron collisions rules transport properties of graphene over a vast range of temperatures and scales, resulting in novel and unexpected phenomena known as hydrodynamic regime [1]. The hydrodynamic regime is described by partial differential equations [2], which, unlike the Navier-Stokes for conventional fluids, account for electronic inelastic collisions and the effect of magnetic fields. Here, we introduce a finite element-based numerical approach that enables us to solve these equations in arbitrary geometries. We compute the resistance in a graphene channel and find a strong dependence with the dissipation at the edges, which is modeled by a characteristic slip length. The narrower the channel, the higher this dissipation. We prove two counterintuitive effects: the Gurzhi effect and the fact that the resistance is higher for a wider crenellated channel [3], due to the lack of uniformity in the velocity field. Further reducing the symmetry may result in electronic whirlpools [4]. Last, we study the effect of the magnetic field and the magnetic viscosity, which causes Hall effect and eases conductivity. We conclude that the geometry has a huge effect on the electrical properties since electron-electron collisions only reveal themselves for non-uniform current fields. Either when modeling graphene devices or when looking for emerging phenomena in unusual geometries, our simulations are an essential tool for a complete understanding of electron viscous flow.

References

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Figures

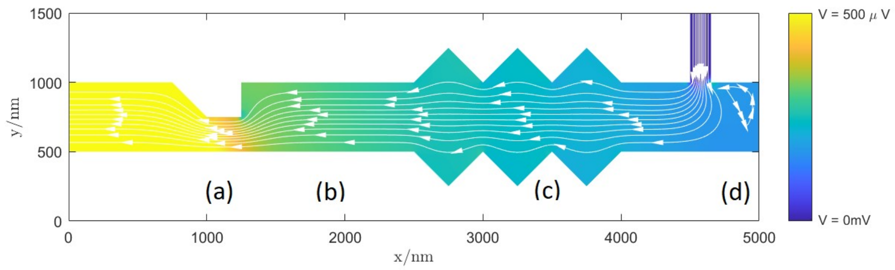

Figure 1: Schematic view of a graphene sample at 150 K, with a carrier density of 10^{12} electrons/cm^2, under a perpendicular magnetic field of 100mT. Electrons, carrying a total current of 100 nA, are injected into the sample by an upper contact, and they leave the sample through another contact on the left. The color scale shows local potentials, which can be used to compute any local or non-local resistance. White lines are streamlines for electron flow. From left to right, we can see (a) a non-symmetrical constriction 250 nm-wide, where there is a large voltage drop due to the reduced width (b) a uniform channel where we can see a Poiseuille flow, together with a Hall voltage, which would increase with increasing magnetic field (c) a crenellated channel where, counterintuitively, the lack of uniformity in the flow results in a larger resistance than in the uniform channel (d) a region of reduced symmetry which leads to an electron whirlpool, where some electrons flow back resulting in negative local resistances, another signature of the viscous electron flow.