Ballistic and hydrodynamic transport: applications in graphene devices

Jorge Estrada-Álvarez[1]
F. Bermúdez-Mendoza[1], J. Salvador-Sánchez[2], E. Diez[2], M. Amado[2], F. Domínguez-Adame[1], E. Díaz[1]
[1]*GISC, Departamento de Física de Materiales, Universidad Complutense, 28040 Madrid, Spain*
[2]*Nanotechnology Group USAL-Nanolab, Dept. Física Fundamental, Plaza de la Merced, Edificio Trilingue, Universidad de Salamanca, 37008, Salamanca, Spain*
jorgestr@ucm.es

The exotic properties of graphene result in a bunch of transport signatures that go beyond Ohm's law [1]. Ballistic and hydrodynamic transport, spanning cryogenics to room temperature, introduces a new paradigm. In particular, the device's geometry determines its electrical response, and specific geometries enable novel applications. First, hydrodynamic transport mitigates the electrical dissipation of nanostructured devices. Among others, in graphene antidot superlattices, superballistic conduction can exhibit an electrical resistance even below the ballistic limit [2]. Although it partially resembles the behavior of a conventional fluid [3], superballistic conduction reveals the unique quantum nature of electrons, with electron dynamics leading to a tomographic effect that further reduces resistance. The simulation and design of optimal geometries also enables lower resistances [4]. Second, the electron fluid exhibits a non-Newtonian response, as revealed by the differential resistance. In particular, we predict a decrease in the differential resistance of geometrically engineered devices, with potential applications in voltage regulators. The hydrodynamic mechanism overcomes the difficulties posed by graphene's gapless nature, which has prevented other designs for electronic devices. In particular, achieving negative differential resistance would enable amplifiers and oscillators, helping to bridge the terahertz gap [5]. Thus, in conclusion, the ballistic and hydrodynamic transport not only constitutes the analog of Ohm's law for graphene, but also enables unique applications.

References

[1] M. Polini, A. K. Geim, Physics Today, **73** (2020) 28.
[2] J. Estrada-Álvarez et al. Phys. Rev. X, **15** (2025) 011039.
[3] J. Estrada-Álvarez et al. Phys. Rev. Letters, **135** (2025) 206301.
[4] J. Estrada-Álvarez et al. Phys. Rev. B **111** (2025) 075401.
[5] J. Estrada-Álvarez et al. 2D Mater. **12** (2025) 015012.
[6] J. Estrada-Álvarez et al. Comm. Phys. **7** (2024)138.

Figures

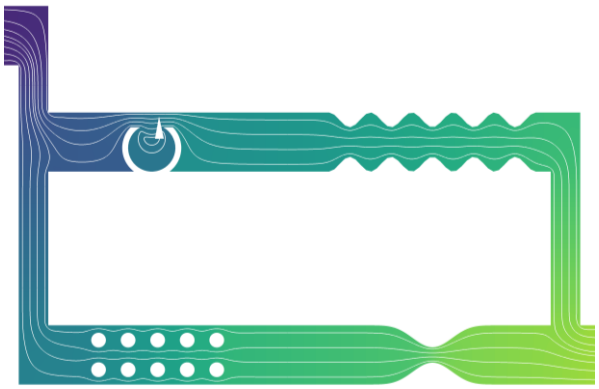

Figure 1: Electron flow in a geometrically engineered device. The hydrodynamic nature of the electrons results in a lower resistance in graphene antidot superlattices. It also enables a modulation of the differential resistance with potential applications in electronics.