Electron hydrodynamics in antidot graphene superlattices

Jorge Estrada-Álvarez[1]

Juan Salvador-Sánchez[2], Ana Pérez-Rodríguez[2], Carlos Sánchez-Sánchez[2], Vito Clericò[2], Daniel Vaquero[2], Kenji Watanabe[3], Takashi Taniguchi[4], Francisco Domínguez-Adame[1], Enrique Díez[2], Mario Amado[2] and Elena Díaz[1]

[1]*GISC, Departamento de Física de Materiales, Universidad Complutense, 28040 Madrid, Spain*

[2]*Nanotechnology Group, USAL-Nanolab, University of Salamanca Pl. de la Merced, Edificio Trilingüe, 37008, Salamanca, Spain*

[3]*Research Center for Functional Materials, National Institute for Materials Science 1-1 Namiki, Tsukuba 305-0044, Japan*

[4]*International Center for Materials Nanoarchitectonics, National Institute for Materials Science 1-1 Namiki, Tsukuba, 305-0044, Japan*

jorgestr@ucm.es

Electron hydrodynamics offers a bunch of exciting phenomena in two dimensional materials [1-2], from Poiseuille flow to electronic whirlpools, as well as the archetypal superballistic conduction [3]. The geometry plays an essential role, and the hydrodynamic effects are enhanced in geometrically engineered devices. We build graphene antidot superlattices with different hole sizes and explore its electrical properties. We find enhanced superballistic conduction, which reduces the electrical resistance of the device below the ballistic limit, and we find a strong enhancement of this effect in the superlattices with the narrowest geometrical features. We explore the effect of the magnetic field, with the magnetoresistance showing up to six quantum and hydrodynamic effects. The non-monotonous character of the superballistic effect with the magnetic field shows four different regions. We perform detailed simulations of the kinetic Boltzmann transport equation to explain all the ballistic to hydrodynamic effects and the enormous dependence of the electrical properties with the device size, another signature of hydrodynamic transport. We developed novel explanations based on [4] to understand the non-monotonous superballistic effect. Our work presents a convenient geometry for studying viscous electron flow and it also contributes to the understanding of hydrodynamic effects.

References

[1] M. Polini and A. K. Geim, Phys. Today **73**, 28(2020).

[2] G. Varnavides, *et. al.* Nat. Rev. Mater. **8**, 726 (2023).

[3] R. Krishma, *et.al.* Nat. Phys. **13**, 1182 (2017).

[4] J. Estrada-Álvarez *et. al.* arXiv:2306.16210 [cond-mat.mes-hall] (2023).

Figures

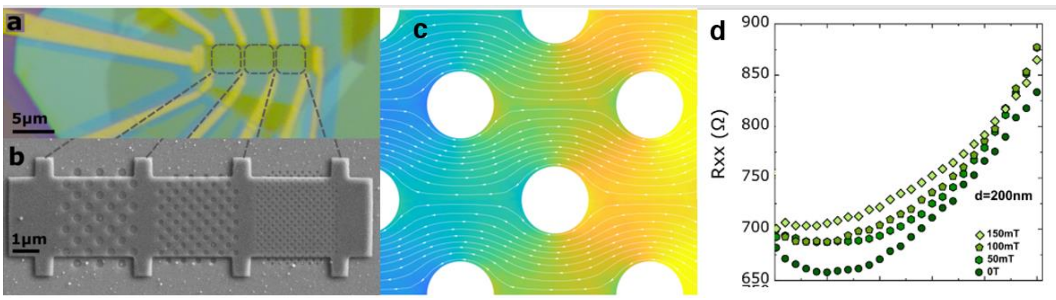

Figure 1: a Micrograph of the graphene device. **b** SEM image of a flake analogous to the one in the device that shows the antidot geometry. **c** Simulation of the Boltzmann transport equation for the ballistic to hydrodynamic transition in this geometry. **d** Experimental results of superballistic conduction in one of the lattices. The decrease of the resistance with increasing temperature, for some magnetic fields, is a hydrodynamic signature.