Imaging the work and dissipation in the quantum Hall state of graphene

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Topology is a powerful recent concept asserting that quantum states could be globally protected against local perturbations. Dissipationless topologically protected states are thus of major fundamental interest as well as of practical importance in metrology and quantum information technology. Although topological protection can be robust theoretically, in realistic devices it is often fragile against various dissipative mechanisms, which are difficult to probe directly because of their microscopic origins. By utilizing scanning nanothermometry [1], we visualize and investigate microscopic mechanisms undermining the topological protection in the quantum Hall state in graphene. Our simultaneous nanoscale thermal and scanning gate microscopy reveals that the dissipation is governed by crosstalk between counterpropagating pairs of downstream and upstream channels that appear at graphene boundaries because of edge reconstruction [2]. Instead of local Joule heating, however, the dissipation mechanism comprises two distinct and spatially separated processes. The work generating process that we image directly and which involves elastic tunneling of charge carriers between the quantum channels, determines the transport properties but does not generate local heat. The independently visualized heat and entropy generation process, in contrast, occurs nonlocally upon inelastic resonant scattering off single atomic defects at graphene edges, while not affecting the transport. Our findings offer a crucial insight into the mechanisms that conceal the true topological protection, and suggest venues for engineering more robust quantum states for device applications.

References

[1] D. Halbertal, *et al.*, Nature **539**, 407-410 (2016)
[2] A. Marguerite, *et al.*, Nature **575**, 628-633 (2019)

Figure

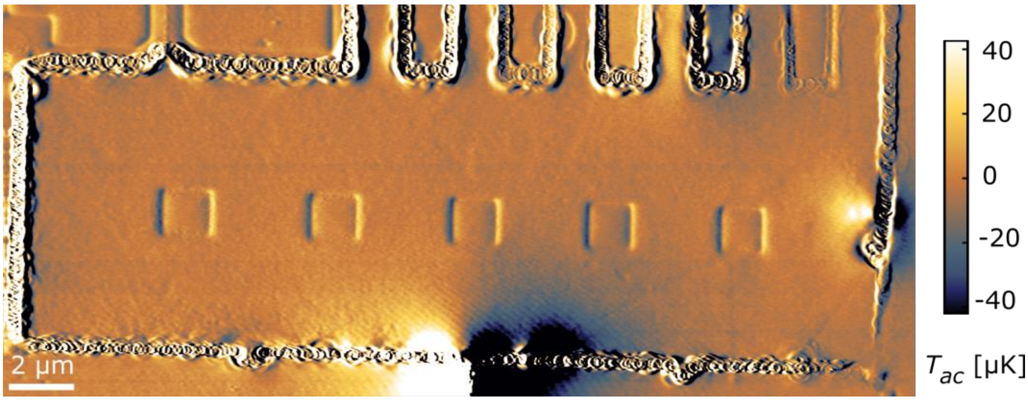

Figure 1: Map of the thermal gradient T_{ac} of a graphene device close to the Dirac point and under strong perpendicular magnetic field showing enhanced dissipation along all edges with no visible dissipation in the bulk.