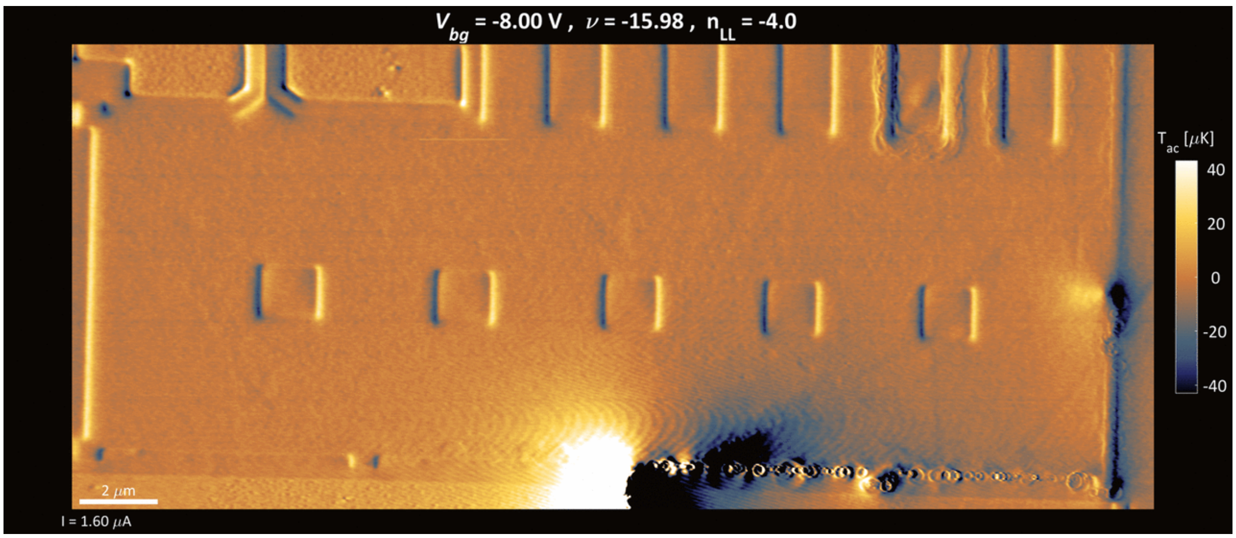
Probing work and heat dissipation in the quantum Hall edges of graphene

October 22 2019



Video 1: A sequence of temperature scans for different backgate voltages V_{bg} incremented from -8 V to 8 V at 4.2 K, B_z= 1 T, and V_{tg}= 8 V. A current Idc is driven from the bottom constriction to one of the top contacts and the value of the current is adjusted with Vbg to maintain total power dissipated in the sample of R_{2p} I_{dc}2= 10 nW. The chirality of the system is counterclockwise for negative Landau levels and clockwise for positive Landau levels. In the video, one can observe the evolution of entropy generation processes, visible as sharp rings along the edges, and the evolution of work generation processes, which appear in the form of larger more blurred features. At large filling factors |ν|≥ 10, predominantly downstream "entropy" rings are visible along the bottom edge of the sample to the right (left) of the constriction for negative (positive) ν. In this case the number of downstream channels is significantly larger than of the upstream edge-reconstructed channels. As a result, the channels are better equilibrated and hence there is less backscattering and less work performed

along the edges. In this situation most of the work is performed at the constriction and the energetic carriers injected at the constriction flow downstream and lose their excess energy through resonant phonon emission at the atomic defects visible as the "entropy" rings. These rings decay over a distance of ~15 μm from the constriction. At |ν|≲ 10, "work" arcs begin to appear in addition to the "entropy" rings along both downstream and upstream directions and the chirality is gradually lost. This behavior originates from backscattering between counterpropagating nontopological channels resulting in work generation along the channels giving rise to arcs. This work, generated along the entire length of the channels rather than at the constriction, in now the dominant energy source that "feeds" the "entropy" rings, explaining the absence of decay in the ring intensity and the absence of chirality. This dissipation, distributed over the full length of the edges, becomes most prominent in the lowest LL, nLL= 0, where no topological edge channels are present. Yet most of the current still flows along the edges due to the presence of one or more pairs of counterpropagating nontopological edge channels. In this metallic state, as well as in higher LL metallic states, instead of the commonly assumed backscattering between the opposite edges of the sample, most of the backscattering occurs between the counterpropagating channels within the edges. This is the reason that in Video V1, we hardly observe any dissipation in the bulk at any value of Vbg, except very close to charge neutrality point, where the overall dissipation in the sample reaches a maximum revealing barely visible rings along the inner edges of the square holes (ν=-0.14 frame). Credit: Weizmann Institute of Science

Combining our nano-SQUID on tip with scanning gate measurements in the quantum Hall phase of graphene we were able to measure and identify work and heat dissipation processes separately. The measurements show that the dissipation is governed by crosstalk between counterpropagating pairs of downstream and upstream channels that appear at graphene boundaries because of edge reconstruction.

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 (see also our previous work) , while not affecting the transport. Our findings offer a crucial insight into the mechanisms concealing the true topological protection and suggest venues for engineering more robust quantum states for device applications. Below are sequences of scans measured on different graphene devices at 4.2 K.

More information: A. Marguerite et al. Imaging work and dissipation in the quantum Hall state in graphene, *Nature* (2019). DOI: 10.1038/s41586-019-1704-3

Provided by Weizmann Institute of Science