Nanoscale mechanical energy dissipation in quantum systems and 2D-materials

Prof. Dr Ernst Meyer, Prof. Dr Martino Poggio, Dr Marcin Kisiel
University of Basel, Department of Physics, Klingelberstr.82, 4056 Basel, Switzerland

Understanding nanoscale energy dissipation is nowadays among few priorities particularly in solid state systems. Breakdown of topological protection, loss of quantum information and disorder–assisted hot electrons scattering in graphene are just few examples of systems, where the presence of energy dissipation has a great impact on the studied object [1]. It is therefore critical to know, how and where energy leaks. Recent experiments with scanning probe thermal imaging (thermometer Squid on tip - tSOT) have proven to overcome the Landauer principle, which defines the dissipation limit for single bit operation. Measurements performed at T=4K reported on dissipated power equal to several *fW* [1]. Pendulum geometry Atomic Force Microscope (AFM), oscillating like a pendulum over the surface, is perfectly suited to measure such tiny amount of dissipation [2,3], since a minimum detectable power loss is of the order of *aW*, well below the tSOT limit. The tip position on the sample is controlled with atomic accuracy owing to a tunneling current line and the enhanced sensitivity allows to distinguish between electronic, phononic or van der Waals types of dissipation [3]. Measurements can be performed in a wide range of temperatures from 5K to room temperature and in magnetic fields spanning from B=0T to B=7T. The design of the sample holder allows to perform dissipation measurements while passing electric current in the plane of the sample surface.

A significant scientific interest, triggered by recent discovery of graphene [4], is focused on 2d–materials. Within the project we will perform energy dissipation measurements on graphene flakes. In the classical case for small carrier velocities, thermal fluctuations give rise to van der Waals dissipation between bodies. In contrast to that, large electron velocities (native to Dirac materials) imply that the energy loss is expected to be governed by proliferation of the hot electrons. Specifically, under such conditions quantum type of losses should be searched, which can be considered as a limiting case of van der Waals dissipation [5]. Poor electron–phonon coupling in graphene implies extremely long mean free path of the hot carriers, sometimes even exceeding the size of the flake. On the other hand, electron scattering was shown to be strongly enhanced in the presence of disorder, mainly due to the small Fermi surface size, which severely constrains energy transfer per collision. It was shown that each defect on the edge of graphene creates a local drain for the excess energy of the hot electrons [1]. As a result, heat dissipation (*fW*) rings are observed in the vicinity of the edge defects. The exact mechanism of such an effect is still scarcely understood and we believe that pendulum AFM will be able to pick up the power dissipation in the vicinity of the graphene edge defects and moreover will shed more light on the detailed mechanism of such processes. We will investigate graphene flakes with different edge structures and also investigate the influence of the substrate and study the role of contamination. The study will be extended to different types of materials namely $NbSe_2$, TaS_2 and Bi_2Te_3.

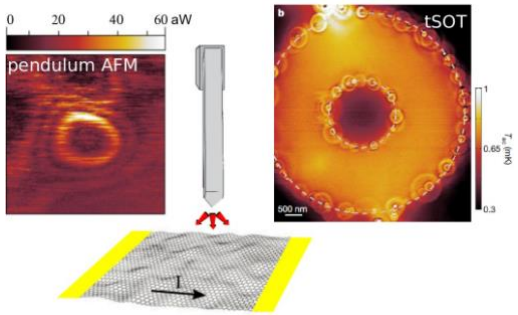

Figure. Ultra–sensitive cantilever oscillating in pendulum geometry on top of the graphene edge, while passing electric current through the sample. Image on the left shows dissipation spectroscopy experiment on Au quantum dots grown onto Cu substrate. The energy dissipation map clearly shows Coulomb blockade dissipation ring with energy disspation burst equal to 50aW. On the right tSOT experiment onto graphene flake while passing current through it. The circular heat dissipation rings of the order of fW are observed.

[1] – D. Halbertal, et.al., *Nanoscale thermal imaging of dissipation in quantum systems*, Nature539, (2016), 407–410.
[2] - B.C. Stipe, et.al., *Noncontact Friction and Force Fluctuations between Closely Spaced Bodies*, Phys. Rev. Lett.87, (2001), 096801.
[3] - M. Kisiel, et.al., *Suppression of electronic friction on Nb films in the superconducting state,* Nature Materials10, (2011), 119-122.
[4] – A. K. Geim, et.al., *The rise of graphene*, Nature Materials6, (2007), 183-191.
[5] – A.I. Volokitin, et.al., *Quantum friction*, PRL106, (2011), 094502.