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Nanoscale thermal imaging of dissipation in quantum systems and in encapsulated graphene[1]

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Energy dissipation is a fundamental process governing the dynamics of physical systems. In condensed matter physics, in particular, scattering mechanisms, loss of quantum information, or breakdown of topological protection are deeply rooted in the intricate details of how and where the dissipation occurs. Despite its vital importance the microscopic behavior of a system is usually not formulated in terms of dissipation because the latter is not a readily measureable quantity on the microscale. While the motivation is clear, existing thermal imaging methods lack the necessary sensitivity and are unsuitable for low temperature operation required for the study of quantum systems. We developed a superconducting quantum interference nano thermometer device with sub 50 nm diameter that resides at the apex of a sharp pipette and provides scanning cryogenic thermal sensing with four orders of magnitude improved thermal sensitivity of below 1 uK/sqrtHz [1]. The noncontact noninvasive thermometry allows thermal imaging of very low nanoscale energy dissipation down to the fundamental Landauer limit of 40 fW for continuous readout of a single qubit at 1 GHz at 4.2 K. These advances enable observation of dissipation due to single electron charging of individual quantum dots in carbon nanotubes, opening the door to direct imaging of nanoscale dissipation processes in quantum matter. In this talk I will describe the technique and present a study of hBN encapsulated graphene which reveals a novel dissipation mechanism due to atomic-scale resonant localized states at the edges of graphene. These results provide a direct valuable glimpse into the electron thermalization process in systems with weak electron-phonon interactions. [1] D. Halbertal, J. Cuppens, M. Ben Shalom, L. Embon, N. Shadmi, Y. Anahory, H. R. Naren, J. Sarkar, A. Uri, Y. Ronen, Y. Myasoedov, L. S. Levitov, E. Joselevich, A. K. Geim & E. Zeldov, Nature (2016), http://dx.doi.org/10.1038/nature19843.

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