Imaging physical phenomena in 2D materials with nanoscale resolution via scanning probe microscopy

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Two-dimensional (2D) materials such as graphene, MoS_2, Bi_2Se_3 possess outstanding electrical, thermal, and mechanical properties. Usually, their electronic properties are the main focus of research, whereas mechanical properties of such nanostructures are much less experimentally explored even for simple graphene structures [1]. At the same time, the nanoscale morphology of atomically thin graphene and MoS_2 films, including rippling at various length scales, inter-layer and 2D material-substrate force interaction are directly modified by the substrate and local environment that in turn changes local nanoscale mechanical properties of a 2D nanostructure.

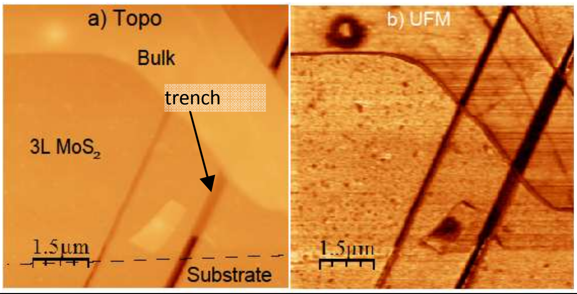

Figure 1. a) 3 layer MoS2 attached to bulk material both suspended over 180 nm wide trench in the substrate. Towards the bottom of the image the substrate can be seen where on the right most trench the MoS2 has been punctured. Image b) shows the corresponding nanomechanical Ultrasonic Force Microscopy (UFM) image where areas dark in colour correspond to less stiff materials. Cantilever stiffness k_c=0.2 N/m, nominal tip radius 10 nm, UFM frequency f_{UFM}=4.3 MHz, amplitude 0.8 nm.

Our group used a combination of scanning probe microscopies that combines low frequency and ultrasonic vibrations [2] and enables mapping of wide dynamic range of stiffnesses from 0.02 to 2000 N/m with the lateral resolution of few nanometres. That allowed us to investigate results of residual stresses in supported graphene layers that revealed themselves as broken mechanical contact at the interface between graphene layer and the substrate, as well as to explore nanomechanical behaviour of few layer suspended graphene, MoS_2 and Bi_2Se_3 films. We directly observed the transition of graphene layer deformation from plate to stretched membrane behaviour, and created nanoscale maps of shell instability for few layer graphene sheets, providing insight to the stresses in the free standing graphene films.

We also addressed the challenge of exploration of thermal phenomena in graphene nanostructures by using nanoscale scanning thermal probe in high vacuum (HV) environment that allowed us to directly map thermal transport in suspended and supported graphene layers with nanoscale resolution, and to explore both ballistic and diffusive regimes of heat transfer [3].

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