Nano-mapping of Surface and Subsurface Physical Properties of 2D materials

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INTRODUCTION

A massive interest in two-dimensional materials (2DM) triggered by graphene (GR) discovery[1] is fueled by the unique electronic, mechanical and thermal properties of these few-atomic-layers-thick materials. While electronic properties of graphene and other 2DM's such as MoS_2, WS, Bi_2Se_3, were extensively studied, their mechanical and thermal properties, equally record-breaking, are much less explored, due to inadequate tools for nanoscale probing of physical properties of atomically thin layers.

Here we overcome this by combining atomic force microscopy (AFM) with specialist nanomechanical, nanothermal and nanoelectrical probes. By applying these to the single and few layer Gr and MoS2 we were able to

- explore the nanomechanical interaction of 2DM's and the substrate, including layers adhesion and stresses;
- observe internal defects in the few layer 2DM's, and defect movement under applied strain;
- map the nanoscale distribution, and quantify electrical charges trapped at the 2DM-substrate interface;
- observe with microscale and nanoscale resolution local electrical and thermal transport in these materials.

EXPERIMENTAL RESULTS AND DISCUSSION

Nanomechanical and nanoelectromechanical mapping. In order to create such nanoscale stress we added small sub-nm amplitude MHz frequency vibration to the AFM sample using Ultrasonic Force Microscopy (UFM) approach. The resulting oscillating strain field propagates through the layers of 2DM to the interface and reveal hidden defects within the layers of 2DM's and the adhesion at the 2DM-interface and linked stress (Fig.1).

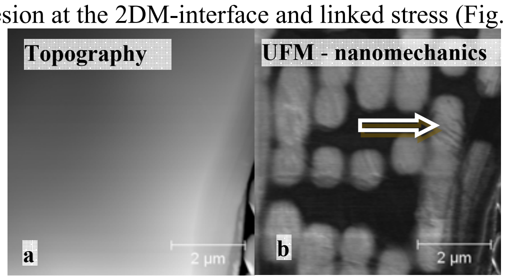

Fig. 1. AFM (a) and nanomechanical UFM (b) images of 50 nm thick multilayer graphene (nano-graphite) flake on the patterned polymeric substrate. UFM reveals area of substrate contact as well as stress-induced defects (arrow).

By adding electrical excitation at frequencies matching ultrasonic vibrations (Fig.2), we can detect electrostatic actuation of 2DM layers revealing hidden charges and ns time scale vibrational dynamics of such nanostructures[2].

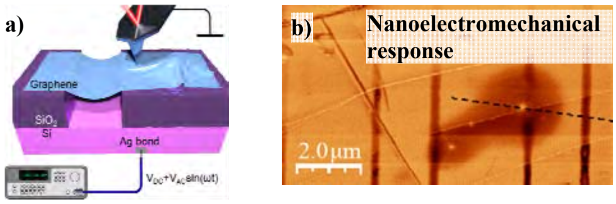

Fig. 2. An electrostatic excitation of the 2DM layer (a) in Contact Electrostatic Force Microscope (C-EFM) creates voltage-dependent nanoelectromechanical response that reveals charges hidden at the 2DM-substrate interface (b).

Nanoscale thermal and electronic transport. By using dedicated AFM probes that can apply and measure heat and current flowing through the nanoscale-sized tip, we can study thermal and electrical transport in the 2DM nanostructures. In Scanning Thermal Microscopy, SThM, a self-heated probe is used as a thermosensor; during probe-sample contact the probe temperature and heat flow are monitored allowing to quantify heat transport in 2DM (Fig. 3). In Scanning Spreading Resistance Microscopy (SSRM), we use highly doped conductive nanocrystalline diamond probe. Electrically biasing the probe, measuring probe current and its dependence on the underlying gate voltage applied to the substrate, we were able to evaluate the electronic transport through the material.

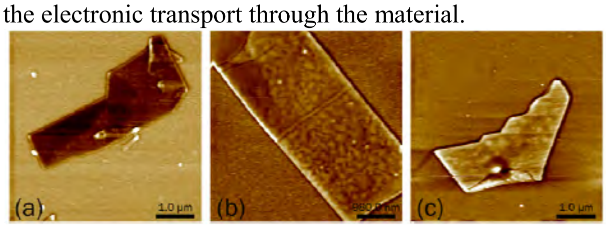

Fig. 3 SThM imaging of (a) Graphene; (b) MoS2; (c) Bi2Se3. Flake thicknesses are 5±1 nm and resting on a 300 nm SiO2 substrate.

CONCLUSION

In this paper we show that nanoscale heat and electronic transport measurements in 2DM layers in SThM and SSRM when combined with the measurements of nanomechanical and charge state of interfaces allows to correctly interpret the measured physical properties of such materials.

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2. http://arxiv.org/abs/1509.00804

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