

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

Oleg V. Kolosov^{1*}, Nicholas D. Kay¹, Jean Spiece¹, Ghazi Alsharif¹, Benjamin J. Robinson¹ and Franco Dinelli²

¹Physics Department, Lancaster University, Lancaster, LA1 4YB, UK

²CNR – INO, Pisa, Italy. e-mail: o.kolosov@lancaster.ac.uk; WWW: <http://www.nano-science.com>

INTRODUCTION

A massive interest in two-dimensional materials (2DM) triggered by graphene (GR) discovery¹ 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 MoS₂, WS₂, Bi₂Se₃, 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).

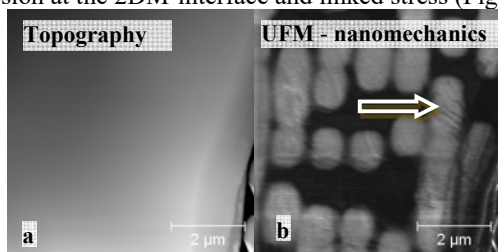


Fig. 1. AFM (a) and nanomechanical UFM (b) images of 50 nm thick multilayer graphene (nano-graphite) flake on the patterned polymeric substrate. UFM reveals area of substrate contact as well as stress-induced defects (arrow).

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 nanostructures².

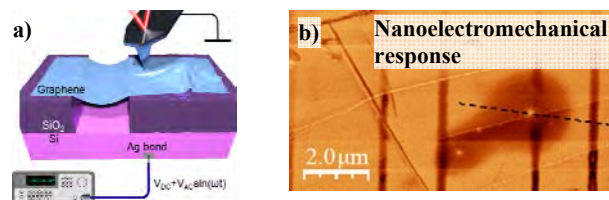


Fig. 2. An electrostatic excitation of the 2DM layer (a) in Contact Electrostatic Force Microscopy (C-EFM) creates voltage-dependent nanoelectromechanical response that reveals charges hidden at the 2DM-substrate interface (b).

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.

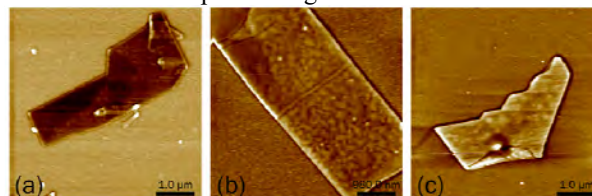


Fig. 3 SThM imaging of (a) Graphene; (b) MoS₂; (c) Bi₂Se₃. Flake thicknesses are 5±1 nm and resting on a 300 nm SiO₂ substrate.

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.

REFERENCES

1. Novoselov K et al, Science. 2004;306(5696):666-9.
2. <http://arxiv.org/abs/1509.00804>

ACKNOWLEDGMENTS

EPSRC EP/K023373/1 and EC FP7 QUANTIHEAT grants are acknowledged by the authors.



Abstracts selected for Oral and Poster Presentations in Graphene Technology (GT) session

No.	Name	Title	ID
1	Mo Song	Preparation and characterization of graphene/polymer nanocomposites with improved mechanical properties	13
2	Yao Tong	Graphene based conductive coatings	16
3	Siham Naima Derra	Polycyclic Aromatic Hydrocarbons Dimers Forming Soot Nanoparticles: a DFT Study	24
4	Lorena Ugarte	A simple method to prepare size-selected graphene by liquid exfoliation for the use in polyurethane foams	27
5	Byung Hoon Kim	Conducting Textiles Fabricated by Graphene Oxide	33
6	A.M. Scaparro	Chemical Vapor Deposition of Graphene on Ge(100) substrates: growth and characterization of the "as grown" system	34
7	Ali Reza Kamali	Large-scale production of high quality graphene in molten salts and its applications	37
8	Zeke Insepov	Acousto-Electronic and Acousto-Plasmonic Properties of Graphene under the Influence of a Surface Acoustic Waves and an External DC Field	43
9	M. Ayan-Varela	Preparation of Few-Layer Graphene and Transition Metal Dichalcogenide Flakes in Aqueous Dispersion through Flavin Mononucleotide-Assisted Liquid-Phase Exfoliation	47
10	Masoud Taleb	Novel approach to ultrasensitive electrochemical detection of organic acids	53
11	Seungdu Kim	Synthesis of Ga ₂ O ₃ nanoparticle on rGO and characterization of methylene blue reduction through photocatalytic reaction	55
12	Won G. Hong	Tunable Energy Storage Media by Graphene Oxide-Based Materials	59
13	Takayuki Suzuki	Neutralization of a graphene grown on the SiC(0001) by means of the Pd intercalation	65
14	David Wynands	OLEDs on Graphene Electrodes	71
15	Pei Kang Shen	Large-scale Production of the Three Dimensional Graphene Powders	81
16	Ana C. Tavares	Effect of Graphene Oxide Sheet Size on the Response of Label-free Electrochemical Biosensors	110
17	Ivan Shorubalko	Large-scale Nanostructuring of Graphene Membranes with Focused Ion Beams	125
18	Oleg Kolosov	Nano-mapping of Surface and Subsurface Physical Properties of 2D materials	126
19	Ilaria Carlomagno	Graphene effects on structural and magnetic anisotropy of Cobalt thin films	132

20	Jan Plutnar	Preparation of Fluorographenes via Direct Fluorination of Graphene	142
21	Elena Lacatus	Self-assembled Biofunctionalized Graphene Oxide Models for Nanomedicine	151
22	Nyan-Hwa Tai	Green reduction of graphene oxide by black soybeans aqueous extract to fabricate graphene-based porous electrodes as supercapacitors	162
23	Nierlly K. A. M. Galvão	Grow of epitaxial graphene on SiC thin film using CO2 laser beam	174
24	José M. Iglesias	Substrate-dependent Out-of-equilibrium Phonon and Electron Dynamics in Photoexcited Graphene	227
25	Tae-Ho Yoon	Mild Oxidation of Graphite to Afford Few-Layer Graphene with Good Property and Good Water Dispersion	232
26	Adriana Marinoiu	Low Cost Doped Graphene for Fuel Cell Electrodes	236
27	Alessandro Migliavacca	Preparation and Characterization of Graphene Oxide Based Membranes as possible Gas Diffusion Layers for PEM fuel cells with enhanced surface homogeneity	243
28	Suddhasatwa Basu	Overcoming CO poisoning of Pt black anode and TPB limitation of CNx nanofiber cathode for PEMFC	262
29	Ahmed Muneer Suhail	A new graphene/Si schottky junction solar cell structure with back contacting graphene	264
30	Fernando Antônio de Araújo Silva	Evaluation of Carbon Dioxide-Nitrogen Adsorption Through Fixed Bed: Modelling and Simulations	272
31	Claudia Cardoso	Surface-assisted formation of graphene nanoribbons on Au surfaces	275
32	Marco Angelo Giambra	Radiofrequency performances of different Graphene Field Effect Transistors geometries	285
33	Salmon Landi	Functionalization of Textiles by TiO ₂ -Reduced Graphene Oxide Nanocomposite as Advanced Photocatalytic Materials	291
34	Anthea Agius Anastasi	A Raman Study of Defective Graphene: Effect of Gallium Ion Bombardment	305
35	Zeke Insepov	Modification of Graphene films with Gas Cluster Ion Beams	308
36	Frederico Sousa	Dilute Magnetism in Graphene	312
37	Ferdinand Hof	Charged Nanocarbons as Effective Reducing Agent in Nanoparticle Synthesis	315
38	Alain Pénicaud	Nanocarbon Dissolving Toolbox : From Food Waste Generation of Multilayer Nanographene to Additive Free, Single Layer Graphene in Water	320
39	Siamak Eqtessadi	Robocasting of Bioglass/ Graphene Composites for Bone Tissue Engineering	321
40	Matat Buzaglo	Graphene Quantum Dots Produced by Microfluidization	322
41	Maxim Varenik	Pyrene Imitating Graphene	323
42	Grzegorz Rut	Impact of trigonal warping on quantum size effect and magnetotransport in bilayer graphene	324
43	Rahul Krishna	Preparation of Co-B/RGO nanocomposite	331