Intercalation between graphene and a metal

A. Kimouche[1] S. Vlaic[1] S. Samaddar[1] S. Martin[1] C. Vo-Van[1] A. T. N'Diaye[2] A. K. Schmid[2] O. Renault[3] O. Fruchart[1] C. Winkelmann[1] N. Rougemaille[1] J. Coraux[1]

[1]Institut Neel, CNRS & Universite Joseph Fourier
[2]National Center for Electron Microscopy, Lawrence Berkeley National Laboratory
[3]CEA LETI

The exploration of the unique properties of graphene, an atomically-thin sheet of sp^2-hybridized carbon, has fostered remarkable efforts since 2004. Recently the possibility to insert graphene into heterostructures, by successive exfoliations of various lamellar materials (e.g. graphite, MoS_2, BN) has opened new perspectives, of which mostly those concerning electronic transport have been considered thus far. Surface science allowed to broaden this scope, from the point of view of both the experimental probes and the preparation of graphene-based heterostructures. Intercalation of various species between graphene and a metallic substrate, a method which has been known since the 1980's [1], encounters renewed interest in this respect. It was for instance shown accordingly that the weak spin-orbit constant of pristine graphene could be considerably enhanced by the immediate proximity of a gold atomic layer [2], or that graphene could recover the electronic properties of free-standing graphene when decoupled from its substrate by an intercalated atomically-thin oxygen layer [3]. Though intercalation is now routinely used in a number of research groups, the mechanisms by which it occurs remain essentially speculated.

Using a combination of microscopy (with electrons and scanning probes) and spectroscopy (X-ray photoemission, Raman, tunneling) techniques we have investigated the intercalation of various species under various conditions between graphene and Ir(111), a prototypical system for high quality [4] quasi free-standing graphene [5]. In this presentation I will present the in situ study of the ultra-high vacuum intercalation of Co ultra-thin films, and of how the magnetic properties of Co are deeply influenced by the interface with graphene [6,7]. I will then address the intercalation of oxygen under atmospheric conditions, and will describe the local formation of an intercalated ultra-thin oxide that it involves as well as the resulting changes in the electronic properties of graphene, which becomes fully decoupled from its substrate [8]. On these two examples I will illustrate the role of defects in graphene (vacancies, edges, wrinkles) in the intercalation process.

[1] A. Y. Tontegode, *Progress Surf. Sci.* **38**, 201 (1991).
[2] A. Varykhalov et al., *Phys. Rev. Lett.* **101**, 157601 (2008).
[3] P. Sutter, J. T. Sadowski, E. A. Sutter, *J. Am. Chem. Soc.* **132**, 8175 (2010).
[4] J. Coraux et al., *Nano Lett.* **8**, 565 (2008).
[5] C. Busse et al., *Phys. Rev. Lett.* **107**, 036101 (2011).
[6] J. Coraux et al., *J. Phys. Chem. Lett.* **3**, 2059 (2012).
[7] N. Rougemaille et al., *Appl. Phys. Lett.* **101**, 142403 (2012).
[8] A. Kimouche et al., submitted (2013).