Transport properties and quantum Hall effect of graphene films grown by CVD on SiC(0001) with in-situ hydrogenation

B. Jouault[1], A. Michon[2]
1) Laboratoire Charles Coulomb, CNRS-Université de Montpellier II, Pl. Eugène Bataillon, 34095 Montpellier Cedex, France

2) CNRS-CRHEA, rue Bernard Grégory, 06560 Valbonne, France

Benoit.Jouault@univ-montp2.fr

Abstract
One of the most promising techniques to produce graphene at the industrial level is silicon sublimation of a silicon carbide (SiC) wafer. In this way, homogeneous epitaxial graphene layers have been obtained on the silicon face of SiC substrates, but the graphene resides on top of the so-called buffer layer or zero layer graphene (ZLG). The ZLG is a reconstructed graphene-like honeycomb lattice with covalent bonds between some of its carbon atoms and the underlying silicon ones. The presence of the ZLG leads to low mobility and high electron concentration in the upper monolayer graphene (MLG). To overcome this problem, various approaches have been developed to dissociate the graphene film from the substrate. The most successful one is post-growth hydrogen intercalation, which drastically decreases the carrier concentration and increases the mobility. Because of the reduced interaction with the substrate, MLG on H-passivated SiC surface has been called "quasi-free standing monolayer graphene" (QFMLG).

As an alternative to SiC sublimation, it has also been shown that graphene can be grown on SiC from an external carbon source. Demonstration of the direct growth of graphene on (0001)SiC has been done by chemical vapor deposition (CVD) with argon as carrier gas (Ar-CVD). In spite of the different carbon supply mechanisms, graphene films obtained by Ar-CVD appear similar to those obtained by the sublimation method. Particularly, both processes lead to the formation of a ZLG on the Si-face and to a strong doping. However, graphene can also be grown by CVD on SiC using hydrogen/argon mixtures as carrier gas. In this case, the presence of hydrogen during the growth has a strong influence on the carbon supply mechanism and the graphene properties. We will present a detailed study of graphene films grown by these CVD methods. The results of angle resolved photoemission spectroscopy (ARPES) measurements, before and after UHV annealing, validate clearly the in-situ hydrogenation of the graphene/SiC interface during the growth. We show that H/Ar-CVD allows to grow either standard epitaxial graphene or quasi-free standing graphene, depending closely on the growth conditions. The key parameters are the growth temperature and, of course, the admixture of argon and hydrogen. Remarkably, a small elevation of the growth temperature allows changing the nature of the graphene film from QFMLG to MLG on a 6R3 interface.

A large part of this presentation will be focused on transport measurements. In our samples, the carrier concentration can be, to some extent, modulated. MLG on ZLG are n-doped, while QFMLG are p-doped. QFMLG have a higher mobility, and the temperature dependence of their electrical resistance is dominated by the graphene acoustical phonons (Fig. 1c). Normally, substrate phonons perturb the graphene magnetoresistance (MR). This is not the case here for p-doped samples, and at moderate magnetic fields, MR reveals a rich physics, including weak-localization (Fig. 1c,1d) and electron-electron interactions. At high magnetic fields and low temperatures, the QHE is observed, both for MLG on ZLG and QFMLG samples. In some case, the QHE is observed with sample sizes of the order of the centimeter. This is a first indication of the good homogeneity of the graphene, which is also confirmed by Raman spectroscopy. Finally, the temperature dependence of the quantum Hall plateaus, as well as the transitions between the plateaus, will be presented and studied. The influence of the disorder and more particularly the influence of the SiC steps (Fig. 1a) on the transport properties will be discussed.

References
B. Jabakhanji, A. Michon, C. Consejo, W. Desrat, M. Portail, A. Tiberj, M. Paillet, A. Zahab, F. Cheynis, F. Lafont, F. Schopfer, W. Poirier, F. Bertran, P. Le Fevre, A. Taleb-Ibrahimi, D. Kazazis, B. C. Camargo, Y. Kopelevich, J. Camassel and B. Jouault, accepted in Phys. Rev. B, 2014.

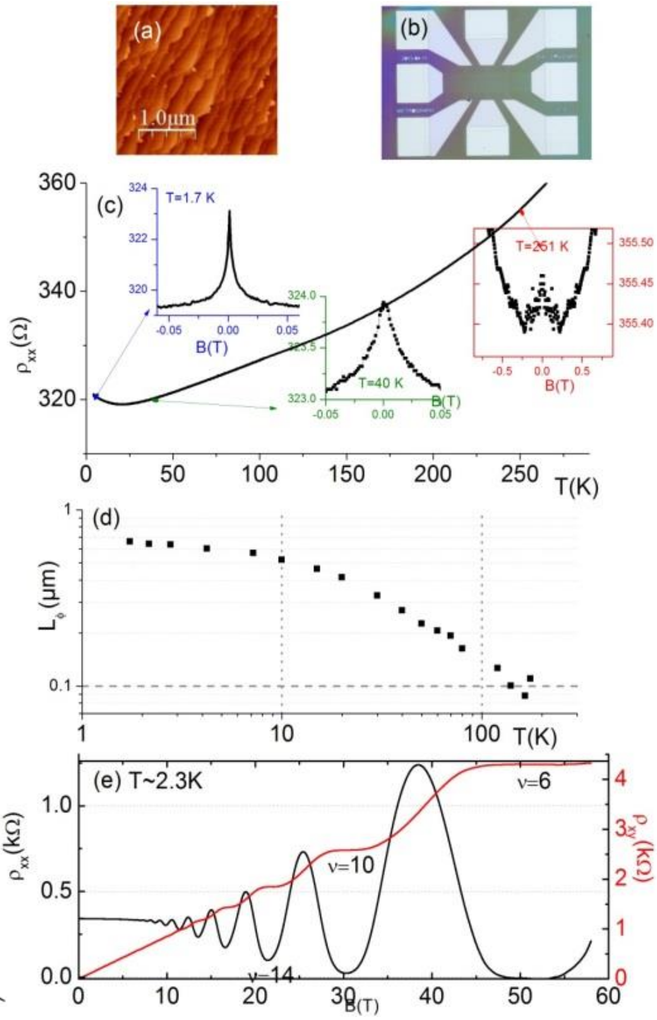

Figure 1: (a) AFM image of the hydrogenated sample surface; (b) The measurements are performed with these Hall bars of width 100 µm and length 500 µm. (c) Temperature dependence of the resistivity, from T=1.7 K up to 290 K. The insets show the MR induced by weak localization at T=1.7 K, 40 K and 250 K. (b) Coherence length as a function of temperature, extracted from fits of the weak localization peak. (c) MR at low temperature (T= 2.3 K) up to B= 58 T, revealing the half-integer quantum Hall effect.