Graphene on Ru(0001): Spatially resolved electronic structure

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The possibility to produce single layers of graphene [1,2] has opened a fascinating new world of physical phenomena in two dimensions. Graphene has already shown that its charge carriers are massless Dirac fermions [3-7] and that it displays an anomalous integer Quantum Hall Effect [3-5] even at room temperature [8]. While ultra-thin epitaxial films of graphite and even "monolayer-graphite" have been grown on solid surfaces by Chemical Vapor Deposition for quite some time [9], the degree of characterization of the films was hampered by experimental limitations. Systems made up of a few graphene layers have been grown on SiC substrates. Recently it has been claimed that a free standing isolated graphene layer is intrinsically corrugated. Charge inhmogeneities have also been observed in nominally undoped samples. Thus, so far, structural ripples and charge inhomogeneities have been observed separately.

We report on a method to fabricate highly perfect, periodically rippled graphene monolayers and islands on Ru(0001) under Ultra High Vacuum conditions. The graphene layers were produced by thermal decomposition at 1000 K of ethylene molecules pre-adsorbed at 300 K on the sample surface. The epitaxial layer of graphene covers completely the surface of the single-crystal Ru substrate over distances larger than a micron and presents a triangular periodicity of 2.4 nm that is due to the coincidence lattice of graphene and Ru, i.e. the lattice of graphene has a size relation with the underlying Ru lattice that implies that 11 carbon honeycombs (0.246 nm) will adjust almost exactly with 10 Ru-Ru interatomic distances (0.27 nm). The weakly interacting, laterally undistorted graphene structure rides on top of the lattice of the substrate, resulting in some C atoms being slightly higher than others.

The periodic charge inhomogeneities in the graphene layer can be visualized directly in the real space by by means of scanning tunnelling microscopy/spectroscopy imaging the spatial distribution of *dI/dV* close to the Fermi energy. Fig.1 shows the spatial distribution of the LDOS below and above the Fermi level. The experimental images are in the upper row at the left and the right of the corresponding topographic image. The bright regions correspond to larger LDOS. In our case, the inhomogeneities in the charge distribution are spatially correlated with the ripples in the graphene layer. The reason behind is the periodic modulation of the potential, due to changes in the metallic screening from the substrate.

This inhomogeneity can be simulated with a tight-binding model which incorporates a periodic potential associated with the structural ripples that induces a shift of the electronic levels and a corresponding charge transfer from conduction to valence bands for some atoms and the opposite in the others. In agreement with the experiments, the calculations show that

the occupied LDOS is larger on the "high" regions of the superlattice, where the potential is at a minimum, while the empty LDOS is larger at the "low" regions of the graphene layers

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Figure 1: The left and right images in the upper panel are maps of *dI/dV* at -100 meV and + 200 meV and reflects the spatial distribution of the LDOS below and above the Fermi level, respectively, for an extended graphene layer on Ru(0001). The central image shows the topographic image recorded simultaneously. The lower panel shows the corresponding calculations for the spatially resolved LDOS for a (11x11) periodically corrugated graphene layer.