ELECTRONIC CORRUGATION OF RIPPLED GRAPHENE EPITAXIALLY GROWN ON Ru(0001)

[1]*Bogdana Borca*, [1,2]*Sara Barja*, [1]*Felix Hermanns*, [2]*Manuela Garnica*, [1]*Juan José Hinarejos*, [1,2]*Amadeo L. Vázquez de Parga*, [1,2]*Rodolfo Miranda*

[1]Departamento de Física de la Materia Condensada CIII, Universidad Autónoma de Madrid, Cantoblanco 28049, Madrid, Spain
[2]Instituto Madrileño de Estudios Avanzados en Nanociencia (IMDEA-Nanociencia), Cantoblanco 28049, Madrid, Spain
bogdana.borca@uam.es

Theoretical predictions [1] and recent experiments [2-4] present graphene, one atom thick carbon layer, as a very interesting material for its extraordinary electronic properties and its application potential [1-7]. Although it has a zero band gap and a vanishing density of states at the Fermi energy, graphene exhibits metallic behaviour due to the topological singularities at the K points in the Brillouin zone. The conduction and the valence bands touch in conical, Dirac, point and the dispersion relation is linear within ±1 eV of the Fermi energy. In a freestanding graphene layer the Fermi energy coincides with the conical points [7-9]. For epitaxial graphene grown on SiC, the substrate-graphene stacking breaks the symmetry within the graphene unit cell opening a gap in the π-band at the Dirac point [10-12], there is also a small doping of the graphene layer. When graphene is grown on metallic surfaces [13], the metal substrates cause the Fermi level to move away from the conical points in graphene, resulting in doping with either electrons or holes [14]. The sign and amount of doping is due to the difference of work function between the metal and the carbon layer and from the chemical bonding between the metal and carbon atoms.

We present an Scanning Tunneling Microscopy/Spectroscopy STM/STS investigation of corrugation of epitaxial graphene monolayer grown on Ru(0001) under Ultra High Vacuum (UHV). The bonding with the substrate occurs through the hybridization of C π-states with Ru d states. Photoelectron spectroscopy shows that the layer bonding is not carbidic and the energy shift of the C 1s core level indicates that the graphene is doped with electrons by the substrate [15]. Graphene and Ru(0001) have different lattice parameters that induce in the graphene overlayer a Moiré pattern in a hexagonal arrangement of protrusions with a period around 2.7-3.0nm. The registry and therefore the hybridization between the carbon atoms and the ruthenium ones changes inside the unit cell introducing spatial charge redistribution in the graphene with electron pockets in the upper part of the Moiré structure. This modulation in the electronic structure has been measured with spatially resolved dI/dV maps [16].

The influence of the modulated electronic structure in the STM images is quite strong. In the upper panel of figure 1, we show 2 STM images measured exactly in the same position but changing the bias voltage applied between tip and sample. As can be seen in the profile the corrugation of the graphene structure changes a factor of two, from a bias voltage of -1V to +1V. In the lower panel we show a compilation of data measured with different tips and different samples. The apparent corrugation of the Moiré superstructure is essentially constant in the interval from -3V to -1V and changes from 0.1±0.03nm at -1V to 0.02±0.03nm at +2V. When the bias voltage applied is higher then +2V the contrast of the Moiré inverse; as can be observed also in a succession of images taken in the same position, at bias voltages $V_b \geq +2V$ (Figure 1d). The bias voltage were the contrast is inverted depends on the distance between tip and sample, a clear indication that different electronic state are involved in the formation of the STM images.

This proves that the electronic effects in this system are stronger than the actual geometric corrugation of the graphene layer. In fact all the scanning tunnelling data can be explained

with a very simple tight-binding model using a flat graphene layer and applying an external potential with the periodicity of the Moiré [16].

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Figure1: a) 18nmx8nm STM images measured with V_b=-1V (left) and V_b=+1V (right) in the same area. b) Line profiles measured on the images shown on (a). c) Summary of the change in the corrugation of the Moiré pattern with the bias voltage, measured for different tips and samples. d) Succession of images (9nmx12.5nm) measured in the same area with different bias voltages, showing the change of contrast from +2V to +3V. The tunneling current of the presented images is constant I=0.1nA.