Quantitative nc-AFM imaging of the atomic scale contrast in epitaxial graphene on Ir(111)

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Scanning probe microscopies have been established as the main experimental tools in studying the atomic scale structure of surfaces. In the case of sp2-bonded carbon (graphene, carbon nanotubes and graphite), both scanning tunneling microscopy (STM) and atomic force microscopy (AFM) have been used to obtain atomically resolved images. However, these images show a rich variety in the atomic contrast depending on the imaging parameters and the atomic termination of the tip apex.[1-4] Extensive DFT calculations have been used to explain this wide variety in measured graphene topographies.[1]

We study these effects experimentally on epitaxial graphene grown by chemical vapor deposition on Ir(111). On the atomic scale, STM shows the complete hexagonal pattern of the carbon atoms in graphene. In addition to the atomic scale contrast, there is a moire pattern caused by the mismatch of the graphene lattice with the underlying substrate atomic lattice. On Ir(111), the moire contrast in STM is mostly an electronic effect and can be inverted depending on the bias voltage and tip termination.[5,6]

Our experimental nc-AFM results with a metallic tip show that depending on the tip-sample distance, the carbon atoms appear either as force minima (attractive regime) or force maxima (repulsive regime). Controlled modification of the tip apex by pick-up of a carbon monoxide molecule changes the tip reactivity. This results in a large change in the atomic scale force contrast, with the more reactive, metal-terminated tips yielding the largest contrast.

[1] M. Ondracek at al., *Phys. Rev. Lett.* **106**, 176101 (2011).
[2] S. Hembacher, F.J. Giessibl, J. Mannhart, C.F. Quate, *Proc. Acad. Nat. Sci.* **100**, 12539 (2003).
[3] M. Ashino, A. Schwarz, T. Behnke, and R. Wiesendanger, *Phys. Rev. Lett.* **93**, 136101 (2004).
[4] B.J. Albers et al., *Nature Nano.* **4**, 307 (2009).
[5] C. Busse et al., *Phys. Rev. Lett.* **107**, 036101 (2011).
[6] A.T. N'Diaye et al., *New. J. Phys.* **10**, 043033 (2008).