STM observation of topological defects and chaos in graphene on a metal

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Order emerges in physical systems as their temperature lowers and symmetries break. Vis-à-vis the concept of order lies that of topological defects. They are low dimensionality objects where order vanishes, and cannot be removed by a continuous transformation of the system. Dislocations for instance are topological defects relative to the translational long range order, and can only be removed by bringing them to the sample edge.

When graphene is supported by a crystalline substrate, their superposition gives rise to a periodic modulation of order (called a moiré lattice). It is usually assumed graphene that this modulation is commensurate with the substrate, so the moiré displays translational long-range order and is said to be superperiodic.

To investigate possible topological defects, scanning tunneling microscopy (STM) is insightful, as it can visualize them at the atomic scale. Here, we exploit a complementary tool known as geometric phase analysis (GPA) [1] to extrapolate local strain fields from our STM images and highlight topological defects.

In graphene on a Re(0001) surface, this analysis reveals domains of moiré slightly shifted and rotated with respect to each other, and separated by domain walls that constitute topological defects in the moiré long-range order. Secondly, within a moiré domain, carbon atoms undergo a non-periodic static distortion wave. This means that in this system, long-rang order does not occur and instead a metastable phase develops, which can be described in an analogy with chaotic dynamic systems [2].

[1] M.J. Hÿtch *et al.*, Quantitative measurement of displacement and strain fields from HREM micrographs, Ultramicroscopy, **74**, 3, 131-146 (1998)
[2] P. Bak, Commensurate phases, incommensurate phases and the devil's staircase, Rep. Prog. Phys., **45**, 6, 587-629 (1982)

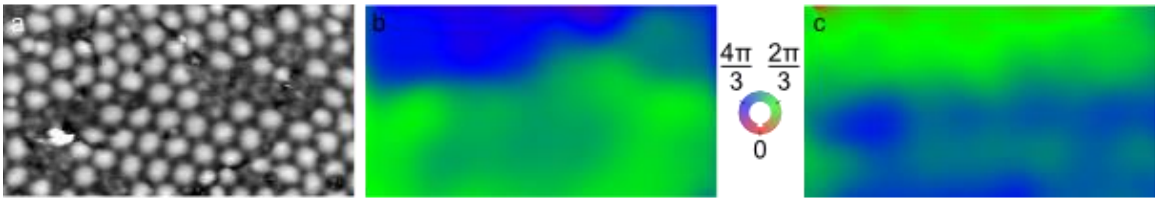

Figure 1 : GPA analysis of graphene on Re(0001). (a) STM topograph with atomic resolution revealing the moiré lattice as well as defective structures. (b-c) Corresponding geometric phase maps of graphene: the color code corresponds to the shift of carbon atoms with respect to a reference position. The contrast between the top left corner and the rest of the image then translates a significant shift between two domains.