Atomic scale characterization of CVD grown graphene using transmission electron microscopy

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Abstract

Graphene shows great potential for future nanoelectronics and related applications due to its extraordinary electronic properties and structure-engineerable nature. Recently various methods of graphene synthesis have been developed and in particular chemical vapor deposition (CVD) and related technologies have given insights to the possibility of large scale application. However functional devices are still far from realization because of the lack of precise control on the synthesis, transfer and other post-growth process to achieve final architectures with the quality and properties required for application. Control and understanding of the atomic structure of synthesized graphene are crucial, because their intrinsic properties are strongly dominated by their atomic structure. Although Raman spectroscopy is commonly used as a powerful technique to statistically characterize the graphene structure such as grain size and presence of defects, we also need some other complementary techniques to fully understand the detailed atomic structures. Following the invention of aberration corrector (AC), atomic resolution transmission electron microscopy (TEM) imaging has become possible on one atom thick layer of carbon [1]. However contrast in atomic resolution TEM images on graphene can be influenced by many parameters such as microscope set up and/or local tilt angle of samples. For instance, to atomically resolve the structure of graphene, we need to control different orders of aberration in the microscope. Even by the use of aberration corrector, the precise measurements and corrections of each aberration are still difficult and a better understanding of each parameter is required for a correct interpretation of the TEM atomic images of graphene.

In this work, we first demonstrate the effect of some important experimental parameters on the atomic scale TEM imaging. Fig.1 shows TEM atomic images of small domain of graphene (flower-like defects) formed inside large one; three images are realized under different conditions of three-fold astigmatism. This result warns that the influence of three-fold astigmatism should be carefully interpreted depending on the crystal orientation of graphene respected to the astigmatism direction. The study on the deformation of atomic images caused by the crystal tilt will be also presented with some examples.

Then the optimized microscope set up is applied to characterize graphene continuous films synthesized on platinum substrate with a specific configuration of CVD set-up. Different types of defect structures are observed in our samples as shown in Fig. 2. These structures are studied with the support of density functional theory (DFT) calculation in order to understand the formation mechanisms and improve the growth process.

References

[1] Z. Lee et al., *Ultramicroscopy*, 112, 39 (2012)
[2] O. Lehtinen et al., *Nature Communications*, DOI : 10.1038 /ncomms3098 (2013)

Figures

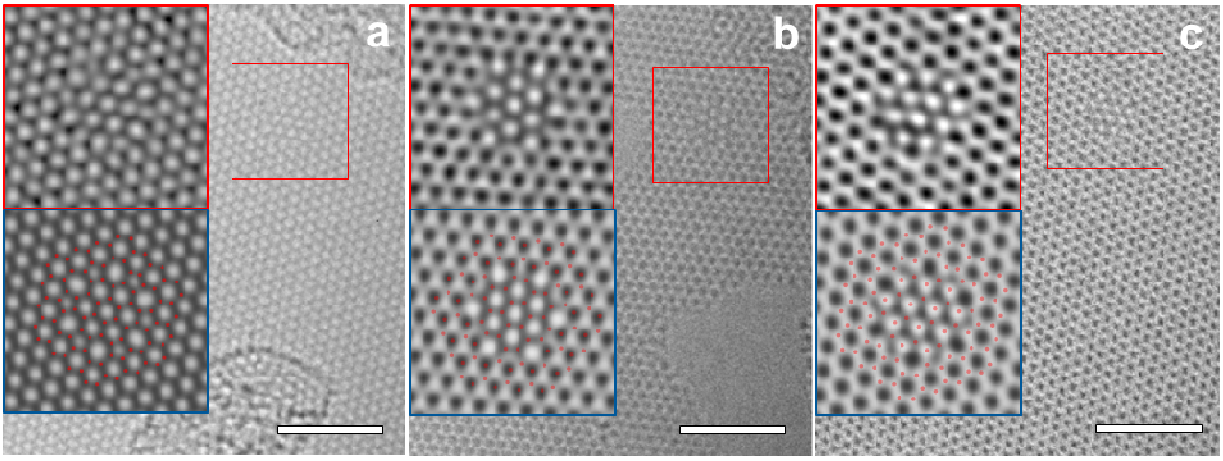

Fig. 1 AC-TEM images of small unit of graphene formed inside large one with three-fold astigmatism (a) 0 nm, (b) 200nm in 30° direction and (c) 200 nm in 60° direction. Low-pass filtered images are shown in red insets and simulated images are shown in blue insets together with used atomic model (red points). Scale bar is 2 nm.

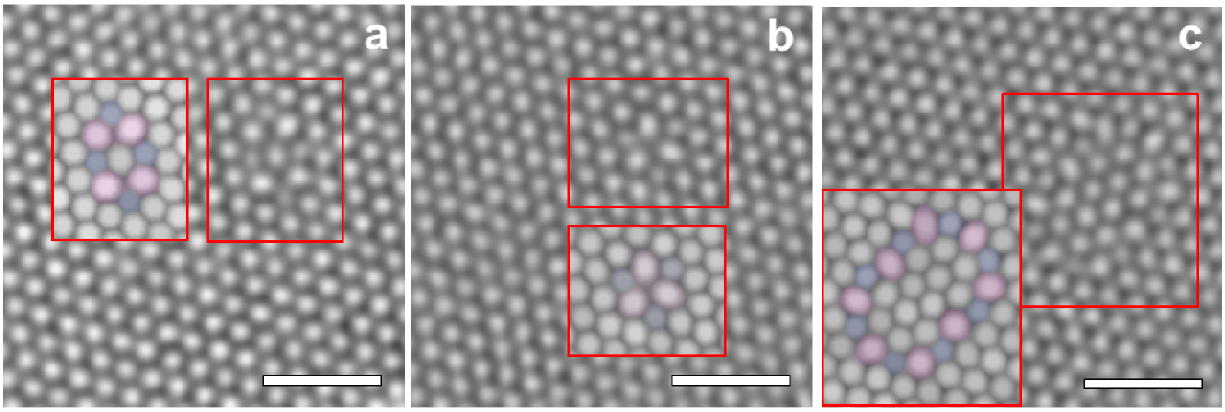

Fig.2 AC-TEM low-pass Fourier filtered images of typical defect structures observed in graphene synthesized with our specific configuration of CVD set-up. Maximum filtered [2] images of defect structures indicated with red squires are shown on insets. Scale bar is 1 nm.