Low-energy electron point projection microscopy/diffraction study of suspended graphene

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Graphene has received much attention owing to its outstanding electrical and mechanical properties. It is also considered to be a model system of two-dimensional (2D) materials. Suspended graphene is a good supporting substrate for observation of nano-objects and molecules in electron microscopy. We have constructed a low-energy electron point projection microscopic/diffractive instrument and used it to characterize suspended graphene samples [1]. We use highly coherent electron beams (energy 50-500 eV) emitted from a single-atom tip for the measurements [2,3]. The schematic of the instrument is almost identical to the low-energy electron point projection microscope (PPM) [4], but the electron-detection screen is designed to be moveable so that the transmission patterns of the samples can be recorded at different sample-screen distances. This permits operation as a typical PPM when the sample-screen distance is large. When the screen is moved in to a small distance behind the sample, high-angle diffraction patterns can be recorded, which can be viewed as divergent beam electron diffraction patterns. The typical PPM image is the zero-order diffraction pattern; the corresponding high-order diffraction patterns provide information about the lattice orientation, periodicity, and ripples of the suspended graphene samples.

We find that long-duration exposure to low-energy electron beams induces aggregation of adsorbates on graphene when the electron dose rate is above a threshold. In the first-order diffraction spots, surprisingly, we observe bright and dark stripes connecting between the adsorbate aggregates, but the stripe patterns are not seen in the corresponding zero-order spot. We have performed numerical simulations of the diffraction patterns to characterize the observed stripe patterns [5]. Our simulations indicate that the contribution from the adsorbates and from three-dimensional distribution of ripples in graphene can be separated by comparing the intensity in the zero- and the first-order diffraction spots. In addition, an out-of-plane ripple produces a similar intensity distribution among all six first-order diffraction spots, whereas an in-plane ripple produces various intensity distributions among the first-order diffraction spots. When imaging with low-energy electrons, the ripples of amplitude 1 Å are sufficiently strong to cause noticeable intensity variations in the first-order diffraction patterns. Thus, very weak ripples associated with strain caused by adsorbates on the graphene surface can be directly visualized and studied. This instrument may also allow lensless coherent diffractive imaging to resolve the atomic structures of thin molecules adsorbed on suspended graphene samples. Further improvement of the experimental setup and development of theoretical reconstruction methods are needed to reach this goal.

References

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