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Properties of two dimensional materials obtained from experiments in a low-voltage aberration-corrected TEM

U. Kaiser[1]

[1]*Ulm University, Group of Electron Microscopy for Materials Science, Ulm, Germany*

We report on structural and electronic properties of two-dimensional materials ob-tained by analytical low-voltage aberration-corrected transmission electron microscopy. Basic crystallographic defects and their peculiarities will be discussed for two-dimensional materials at the atomic level. Thus, we report the atomic structure of point defect and -clusters [1], the full life circle of dislocations [2] and the movements of grain boundaries in grapheme [3]. In addition, we unravel the atomic structure of the amorphous phase (graphene, SiO_2) in direct space just from single-atom-based analysis of high-resolution TEM images [5, 6]. As the energetic electron beam is interacting with the specimen via transferring energy to the atoms, structural transformation between different phases can be followed atom-by-atom [7, 8, 9]. In addition, physical properties such as the knock-on damage threshold is determined from controlled direct space experiments and precise measurements of high-resolution TEM images of graphene and MoS_2 [8, 7]. However beam-electron interactions with the specimen are also restricting imaging the pristine structure of a sample. It can be suppressed by simply limiting the total electron doses on the samples. Limited electron doses, however, result in worse signal to noise ratios. Here, a quantitative approach for estimating the visibility of objects in TEM images with limited doses will be presented [10]. Another traditional approach to suppress electron-induced damage during HRTEM observation is to employ an efficient cleaning procedure [11] and the protective coating of sensitive materials. This old approach will be taken to its extreme, when radiation sensitive materials are enclosed inside carbon nanotubes [12] and between two graphene layers [13]. We show moreover the advantage of lowering the accelerating voltage for imaging the pristine structure of low-dimensional materials [14]. [4] P. Wachsmuth, R. Hambach, M.K. Kinyanjui, et al., Phys. Rev. B B 88, 075433, (2013) [5] P. Y. Huang, S. Kurasch, A. Srivastava, et al. Nano Lett. 12(2), 1081, (2012) [6] P. Y. Huang, S. Kurasch, J.S. Alden, et al., Science 342, 224, (2013) [7] H.-P. Komsa, J. Kotakoski, S. Kurasch, et al., Phys. Rev. Lett. 109, 035503 (2012) [8] C Meyer, F Eder, S Kurasch, et al. Physical Review Letters, 108, 196102. 2012. [9] B. Westenfelder, J. C. Meyer, J. Biskupek, et al., Transformations of Carbon Adsorbates on Graphene Substrates under Extreme Heat, Nano Letters, 11 (12), 5123-5127, 2011 [10] Z. Lee, H. Rose, O. Lehtinen, et al., Ultramicroscopy (2014), DOI 10.1016/j.ultramic.2014.01.010 [11] G. Algara-Siller, S. Kurasch, M. Sedighi, et al., Appl. Phys. Lett. 103 (2013) 203107 [12] T. Zoberbier, T. W. Chamberlain, J. Biskupek, et al., J. Am. Chem. Soc. 134 (2012) 3073-3079 [13] G. Algara-Siller, S. Kurasch, M. Sedighi, et al., Appl. Phys. Lett. 103. 203107, (2013) [14] U. Kaiser et al. Ultramicroscopy, 111, 8, 1239, (2011) [15] Fruitful cooperation within the SALVE project and financial support by the DFG (German Research Foundation) and by the Ministry of Science, Research, and the Arts (MWK) of Baden-Württemberg are gratefully acknowledged.

[1] *J. Kotakoski, J. Meyer, S. Kurasch, et al. Physical Review B, 83 (2011),* ***[2]*** *O. Lehtinen, S. Kurasch, A.V. Krasheninnikov et al. Nature Communications 4, 3098, (2013),* ***[3]*** *S. Kurasch, J. Kotakoski, O. Lehtinen, et al. Nano Lett. 12 (6), 3168, (2012)*

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