Keynote Lecture

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

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We report on structural and electronic properties of two-dimensional materials obtained 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 graphene [3]. In addition, we unravel the atomic structure of the amorphous phase (graphene, SiO₂) 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 MoS₂ [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].


Keywords: low-voltage transmission electron microscopy, crystallographic defects in two-dimensional materials, amorphous phase