Graphene [1] is one of the most investigated 2D-structures in the last decade. Some efforts were undertaken [2,3,4] to determine the projected potential (PP) of graphene for different layer thicknesses. Off-axis electron holography (EH) [5] allows to recover numerically the image wave and, for known residual aberrations of the TEM, to reconstruct the object exit wave. The accuracy is significantly increased by using a Cs-corrected TEM [6,7].

CVD graphene transferred to holy carbon was cleaned using active carbon or Al2O3 powder at ~200°C at the sample surface [8] (fig.1a). Because of the quite long time needed for TEM-adjustment in EH-mode, searching for adequate sample locations and positioning in EH, new contamination appears (fig. 1b,c). Consequently, the graphene layers are often not perfectly clean and the PP is generally higher than the ideal values, cleanliness of the graphene layers proves out to be essential for accurate results.

The illumination of our Cs-corrected FEI Titan 80-300 TEM with rotatable Möllenstedt biprism, was optimized for EH at 80kV [2], where beam damage of graphene is reduced. Taking the C1–C3 condenser lens setting [9], the elliptical illumination could be optimized and using a reduced extraction voltage by ~2kV, a decrease of the electron energy distribution was achieved. Finally the hologram contrast could be noteworthy improved [2]. The experiments till now show, presumably due to contamination, a quite large dispersion and a tendency to higher values than the calculated ones. Using the independent atom model (IAM) and/or the density functional theory (DFT), image simulations and calculations of the PP, were made using the programs QSTEM [C. Koch] and JEMS [P. Stadelmann].

To characterize the local thickness and the PP of graphene, we took holograms in high-resolution TEM. The analysis of the profile lines in the reconstructed object phase allows the determination of the local thickness variations (fig. 2). Contamination and the EH-restriction, to use only object areas next to vacuum, make difficult to find large ideal uniform sample areas. Phase jumps, related to thickness variations, show for most of the results up to now, phase shifts of <0.08 rad at a phase detection limit per single hologram of ~2π/70. To conclude our studies, additional results with better statistics will follow.


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Fig. 1: Specimen contamination state immediately after insertion in the TEM (a), about three hours later (b) and at the end of the TEM-session (c).

Fig. 2: Reconstructed phase image from the object exit wave of graphene layers at vacuum, showing some contamination (a) with the phase profile along the arrow (b). Holograms were taken with Cs-corrected FEI Titan 80-300 TEM at 80kV in HRTEM mode.