How to clean a sample when sputtering is not possible because the sample has only one atomic layer?

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In recent years interest in two-dimensional materials has experienced a strong rise and they have been a hot topic ever since the discovery of a single layer graphene in 2004 [1]. As they entail promising properties for future devices, a great effort was put into research for tunnelling devices, tuneable light-emitting diodes and molecular sieving possibilities [2-4]. However, two-dimensional materials have not only good prospects in regard to applications but are also interesting for fundamental research: We study ion-solid interaction where 2D materials come with the possibility of ion transmission so that ions can still be detected after the interaction with the material for instance [5].

One major issue concerning atomically thin materials is handling contaminations. Graphene for example is known to be hosting many contaminations mostly in the form of hydrocarbons, water and residuals from production and transfer processes [6]. In the case of a one-layer material, popular cleaning techniques like sputtering are detrimental to material stability, so other techniques need to be addressed.

We study the interaction of highly charged ions and two-dimensional materials. The ions (Xe^{1+} to Xe^{44+}) are produced in an electron beam ion source (EBIS) and individual charge states are extracted with kinetic energies in the range of 1-400 keV. After transmission through the sample, the exit charge states of the ions are separated by means of a pair of deflection plates. Additionally, an electron emission statistics setup detects the yield of emitted electrons. Coincidence measurements of transmitted ions and emitted electrons are possible and also allow determination of the time of flight of the incident projectiles and hence determination of the energy loss within the interaction [7,8].

Here, we want to present two techniques to clean our samples *in situ* before and during measurements based on presented possibilities in [9]. Heating and laser annealing both will be discussed regarding achieved cleaning results. Cleaned samples were analysed with ion beam spectroscopy and atomically resolved (scanning) transmission electron microscopy (S)TEM.

STEM measurements confirm our results and indeed show clean areas surrounded by areas with thick contamination. The latter are invisible for our ion beam spectroscopy, since ions get stuck or are transmitted with large energy loss and hence significantly longer time of flights which can be discriminated in our analysis (cf. figure 1).

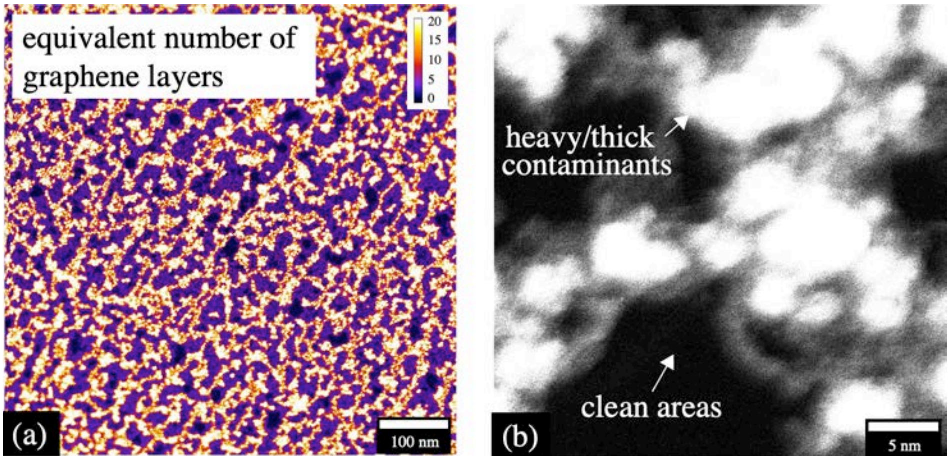

Figure 1 - STEM images of a single layer of graphene after cleaning procedure. The colour code in (a) shows the thickness of the sample in equivalent numbers of graphene layers. In (b) clean areas and areas with heavy/thick contamination are marked.

Finally, a comparison of measurements with cleaned samples to ones performed prior to the installation of cleaning procedures will complement this contribution.

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