Manipulation of WSe_2-monolayers on the nm-scale

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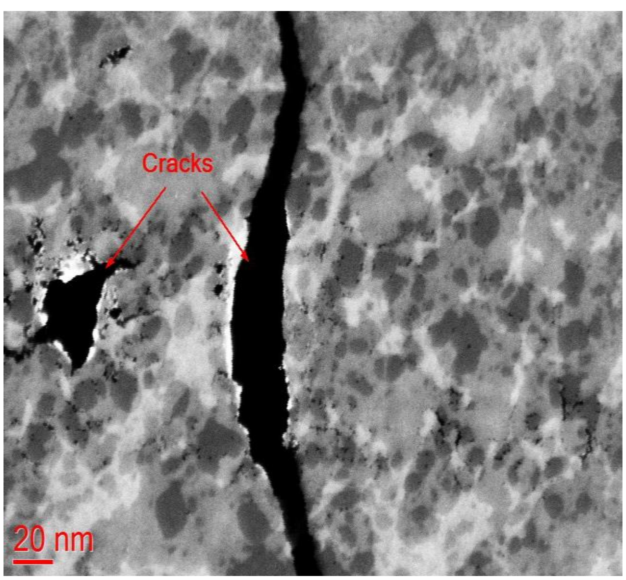
The manipulation of 2d-semiconductors has proven to be promising in order to build smaller efficient nanoelectronic and optoelectronic devices [1]. It has been shown that single photon emitters can be locally formed and have an excellent spectral stability [2]. By bending the crystal lattice of two dimensional WSe_2 it is possible to control these properties on the micro [2] and nanoscale [3]. With the focus on creating local spots of single photon emitters we show here that cutting patterns and folding edges of monolayers can be provided by a combination of conventional transmission electron microscopy (TEM) and scanning transmission electron microscopy (STEM) techniques (Fig. 1,2).
Using STEM we drill holes, cut lines and cracks into the monolayer. In order to image these structures afterwards much shorter dwell times are used to reduce further damaging (Fig. 1). By homogeneously irradiating the cuts which can be provided by conventional TEM the edges start to fold and cracks are ripping further (Fig. 2). We observe that the ripping of the cracks during irradiation tend to follow the camouflage-like structure which is visible within the STEM measurements (Fig. 1). Cracks specially evolve at thinner regions of the monolayer. Electron energy loss spectroscopy (EELS) investigations revealed SiO_2 contamination on the surface. Energy filtered TEM images of the silicon distribution using the $L_{2,3}$ edge show structures very similar to STEM HAADF images. This indicates that the STEM contrast is mainly due to silicon patches. The SiO_2 most likely stems from sample preparation involving the polymer Polydimethylsiloxane, which is used as an adhesive during the transfer and exfoliation process.
The investigation of the influence of surface contamination is important because it is a major obstacle for precise sculpturing of monolayers [4]. Also damaging the monolayer during imaging is still not negligible in spite of short dwell times. Making use of self-healing properties at higher temperatures could further improve the precision of the sculpting process which has been shown for graphene-monolayers [4].



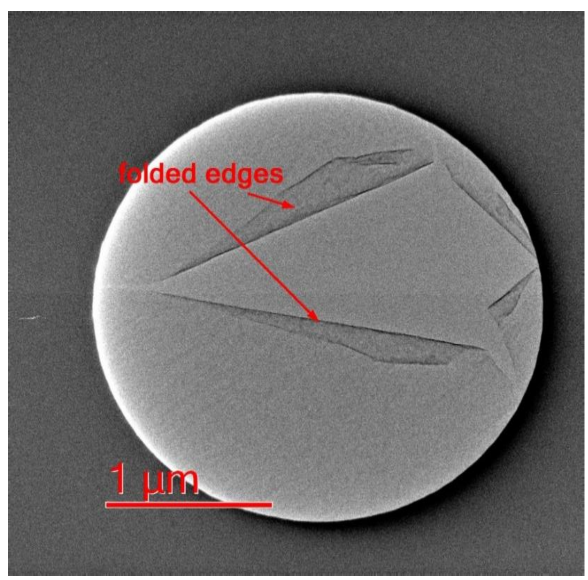


Fig. 1 (left): Production of holes and cracks at the nm-scale on WSe_2-monolayers. In order to cut and investigate holes inside the monolayer STEM HAADF was used.

Fig. 2 (right): Under extensive irradiation using conventional TEM the cracks evolve and the edges start to fold.

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[4] Q. Xu, et al. "Controllable Atomic Scale Patterning of Freestanding Monolayer Graphene at Elevated Temperature." *ACS Nano* **7**, 1566-1572 (2013).