Effect of Electron Beam Irradiation on Electrical Properties of WS_2 Nanotubes: An in-situ/in-operando Study

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Semiconducting 1D materials such as nanowires or nanotubes often provide superior properties to its bulk counterparts which can be well utilized in various nanodevices [1, 2]. During the fabrication process of such nanodevices, electron beam is often very widely used, either for observation or for direct fabrication of the devices, e.g., making electrical contacts by electron lithography. However, it is well known that electron beam can induce both reversible and irreversible changes to the 1D material or to the underlying substrate [3, 4]. Subsequently, device properties are often altered. Considering WS_2 nanotubes, this effect is very sparsely reported in the literature. The exception is the effect of high energy electrons in TEM [4,5]. To our knowledge, consequences of electron irradiation with lower energies (1-30 kV) and with doses that are commonly used for sample observation or in lithography processes were not systematically examined yet.

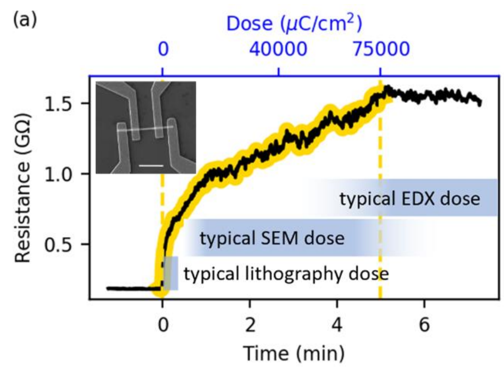

Fig.1: Change in nanotube's resistance during electron irradiation compared with typical doses used in electron lithography, SEM observation or EDX elemental analysis. Inset shows example of contacted WS_2 nanotube. Scale bar is 2 µm.

In this contribution, we will show that electron irradiation caused by routine device observation in electron microscope is enough to significantly change the result of electrical analysis of individual WS_2 nanotubes contacted on a planar substrate (Fig. 1). Using in-situ electrical measurement directly inside electron microscope, we address important aspects regarding the influence of electron irradiation onto electrical properties of WS_2 nanotubes.

According to our experiments, electrical properties of WS2 nanotubes are significantly changed even for short electron exposure with mild SEM imaging conditions (few seconds, 250 pA), irrespective of the acceleration voltage choice (1-30 kV). The change is generally long-lasting (days to months). We also decoupled the role of electron irradiation on the nanotube and the contacts. Moreover, we examined the origin of the changes observed and our experiments revealed that the main cause is field-effect induced by the substrate charge implanted by the electron beam. We used in-situ Kelvin Probe Force Microscopy to visualize the charge implanted in the substrate and we confirmed the role of substrate by fabricating and irradiating suspended freestanding WS2 nanotubes. Our data show that, in general, the electron dose should be considered when planning the experimental workflow which includes electron beam exposure.

Acknowledgements:
This research is co-financed from the state budget by the Technology agency of the Czech Republic under the National Centre of Competence Programme. no. TN02000020.

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