Understanding the Effect of Electron Irradiation on Nanotube Devices to Improve Prototyping Routines

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Semiconducting low dimensional materials, including 2D materials, nanowires and nanotubes, are becoming increasingly attractive for various nanodevice applications[1,2]. A key step in the fabrication of such devices is electron beam lithography (EBL), which is widely used for defining nanoscale features and forming electrical contacts. However, electron beam exposure—whether during lithography or imaging—can induce both reversible and irreversible modifications in the 1D material and the underlying substrate[3,4], altering device performance.

In this work, we demonstrate that even routine electron microscope imaging can significantly influence the electrical characterization of WS_2 nanotube-based devices[5]. Using in-situ electrical measurements inside an electron microscope, we systematically investigate how electron irradiation affects the electrical behavior of WS_2 nanotubes on insulating oxide substrates (Fig. 1). Our results show that short electron exposure, comparable to quick SEM observation or typical e-beam lithography doses, leads to persistent changes in conductivity, independent of the acceleration voltage (1–30 kV). These modifications last from days to months and are primarily attributed to field-effect doping caused by substrate charging. We confirm this mechanism using in-situ Kelvin Probe Force Microscopy, which directly visualizes charge implantation in the substrate, and by comparing the response of suspended WS_2 nanotubes, which remain unaffected. The trapped charge could be dissipated by annealing at elevated temperature. This effect is likely to be even more pronounced in 2D materials or thin-channel devices, where the field effect is more effective in modulating the electronic properties.

Our findings highlight the critical need to consider electron irradiation effects when designing experiments involving electron beam lithography or imaging. Unintentional charge implantation may significantly impact device performance and should be carefully managed to ensure reliable electrical characterization and reproducible device fabrication.

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[1] Ch. Zhang et al., *Appl. Phys. Lett*. 100, 243101 (2012)
[2] R. Levi et al., *Nano Lett*. 13, 8, 3736 (2013),
[3] K. K. Neelisetty et al., *Microscopy and Microanalysis*, 25, 592 (2019)
[4] K. Ding et al., *Nanotechnology*, 23, 415703 (2012)
[5] M. Kovařík et. al, *ACS Appl. Electron. Mater.* 2024 6 (12), 8776-8782.

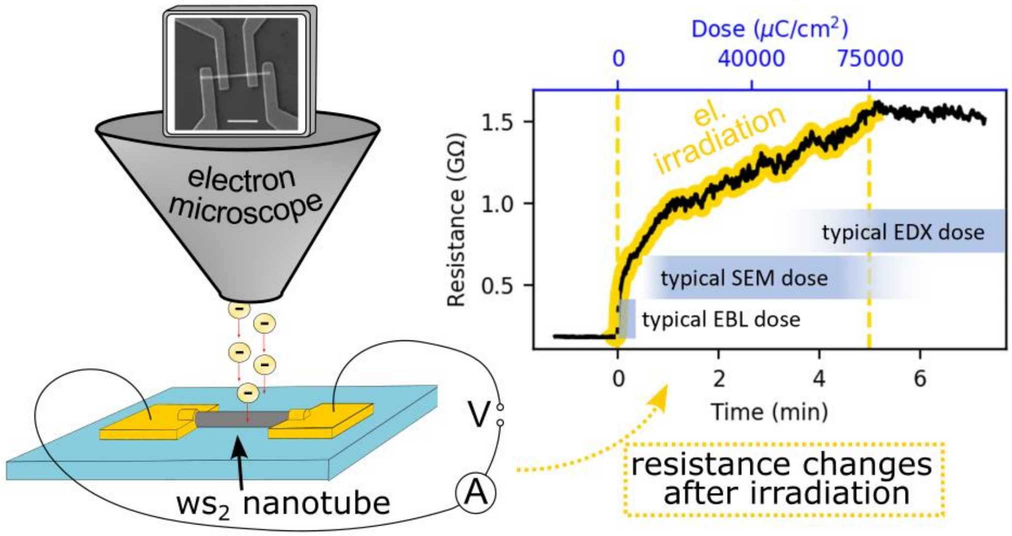

Figure 1: Schematic illustration of the electron irradiation experiment and its results. The resistance of a nanotube device increases rapidly within first seconds of electron irradiation. Reprinted from: Kovařík M. et. al, *ACS Appl. Electron. Mater.* 2024 6 (12), 8776-8782.