# Electrical properties of collapsed $MoS_2$ nanotubes

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## INTRODUCTION

Molybdenum Disulfide ($MoS_2$) is a promising material for future high-performance and ultra-low-power electronics. $MoS_2$ nanotubes (NTs) grown by chemical vapor transport (CVT) are known by high structural perfection.[1] They were used as channels in field-effect transistors[2] and as electron field emitters[3]. They can confine electromagnetic fields within their walls[4] and their transport properties indicate a single quantum-level transport[5]. Despite the recent surge in interest in $MoS_2$ monolayers and NTs, the collapsed NTs in a shape of nanoribbons (NRs) remain unexplored.

## EXPERIMENTAL STUDY

The $MoS_2$ NRs were synthesized via a CVT reaction at 1010 K in a quartz ampoule, utilizing iodine as the transport agent. The NRs were transferred from the quartz ampoule to a p-doped silicon substrate using adhesive tape method. Vibrational properties of the NRs were studied by Raman spectroscopy using a WITec Alpha 300 RS scanning confocal Raman microscope. Atomic Force Microscopy (AFM), and Kelvin Probe Force Microscopy (KPFM) were performed using an Omicron UHV VT-AFM system (Scienta Omicron), operating at $10^{-9}$ mbar, with the modulation voltage for KPFM applied to the tip. Charge transport properties, mobility, and retention were investigated through charge injections in contact AFM mode with voltage applied to the tip.

## RESULTS AND DISCUSSION

Resonant Raman spectroscopy revealed additional bands at 379, 419, 589, and 629 $cm^{-1}$, compared to non-resonant[2], indicating that the sample consists of only a few layers[6]. Since the thickness of the NR under investigation is about 17 nm, which corresponds to around 13 layers in the NR's wall, the presence of these bands suggests that some of the layers of the NR are partially split. A high intensity of the band at 419 $cm^{-1}$ in the central part of the NR could mean that the splitting is stronger there than at the NR edges. A lattice strain effect on lattice vibrations is also possible.

A contact current imaging spectroscopy (CCIS) revealed longitudinal wrinkles on the NR surface, with elevated regions found to be more conductive than the depressed areas. The conductance of both elevated and depressed regions is higher at positive voltages than at negative ones. However, conductivity varies between the left and right side of the NR, likely due to differences in the NR-substrate contact. Furthermore, the rounded edges of the NR, where molecular layers are strongly curved but not broken exhibit varying conductivity. While some parts display zero conductivity, the others show much higher conductivity than the central part of the NR, suggesting an electron confinement effect.

Charge injection experiments revealed that both hole and electron injections altered the NR's work function. Additionally, charge injection also induced changes in the NR's topography, as the surface became more wrinkled and the NR rotated around its longitudinal axis, which is attributed to the rotational component of the reverse piezoelectric effect.[7]

## CONCLUSION

The electrical properties of $MoS_2$ NRs were investigated for the first time. The presented findings highlight the need for further research of the electrical properties of $MoS_2$ NTs, as variations in these properties could significantly influence the performance of devices constructed from them.

## REFERENCES

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