Carbon Nanotube Functionalized Spider Silk for Strain and Humidity Sensing

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Introduction

Spider silk is a natural material possessing exceptional toughness and complex functions. It is also a versatile scaffold on which additional functions can be built for various applications. We have developed a simple water-based method of functionalizing spider silk fibers with a thin, flexible, and porous aminated multi-walled carbon nanotube (CNT) network (CNT-SS) that are electrically conducting and sensitive to strain and humidity changes.

Experimental

The functionalization was done by first mixing the neat silk fibers with a dry CNT powder, followed by wetting, pressing, and shearing the mixture. SEM images were obtained by JEOL JSM-7410F SEM. A Leica Ultracut E microtome was used to obtain 90 nm thin CNT-SS sections for TEM (JEOL JEM-ARM 200F) studies.

Results and Discussion

The CNTs adhere very well to the surface of the silk fiber (**Figures 1a and 1b**). The annular CNT coating is uniform and has a typical thickness of ~ 80 nm (**Figures 1c and 1d**). The CNT-SS fibers are conducting and exhibit a Variable Range Hopping behavior (**Figure 2a**). The resistance is sensitive to strain, allowing their use for heart pulse monitoring (**Figure 2b**). Likewise, the fibers can be used to monitor relative humidity changes (**Figure 2c**).

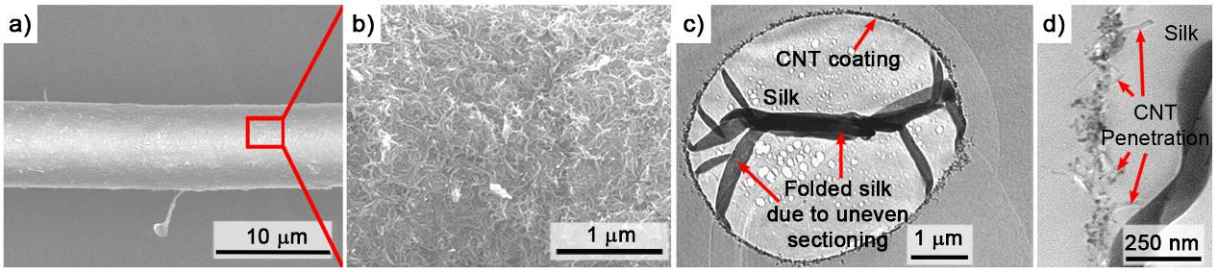

Figure 1. SEM and TEM images of a single CNT-SS fiber. A lower (a) and higher (b) magnification SEM image showing mat-like CNT network. A lower (c) and higher (d) TEM image of CNT-SS cross section showing uniform coating and CNT penetration.

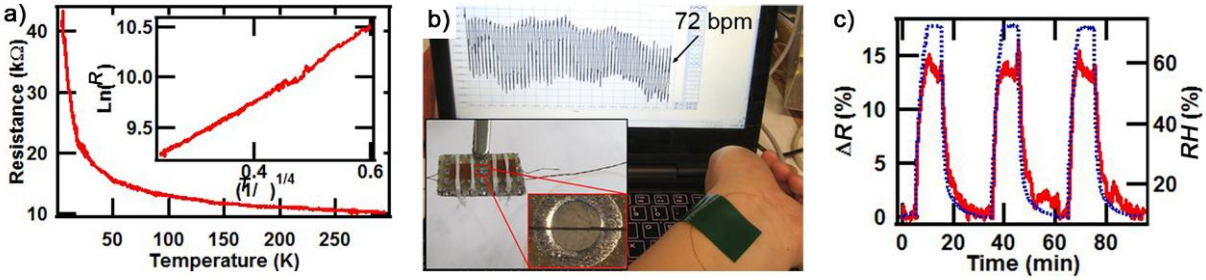

Figure 2. Electronic properties of CNT-SS. (a) Temperature dependent resistance showing Variable Range Hopping behavior. (b) Strain dependent resistance during heart pulse monitoring. (c) Cyclic relative humidity (*RH*) test (solid line: ΔR, Dotted line: *RH*).

Conclusions

We have developed a simple water-based method of producing carbon nanotube functionalized spider silk fibers. Proof-of-concept heart pulse and humidity sensors based on the CNT-SS fibers have been demonstrated.

Acknowledgements

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