SuperStrand CNT-Biopolymer Multi-Functional Textile Fibers for Capacitive Energy Storage

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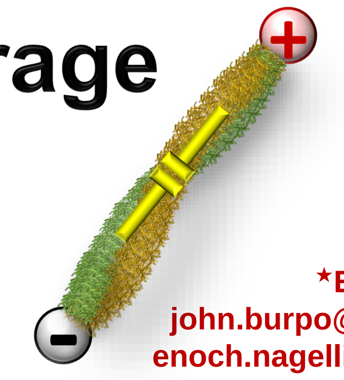

Abstract

Biological hydrogels can serve as 3-dimensional bio-template for tunable nano-porous materials that serve both as electrochemically active high surface area and structural material. We present a general approach to (1) form a biological composite fiber using crosslinked oxidized carbon nanotubes with cellulose nanofibers, polyvinyl alcohol, and/or DNA, and (2) demonstrate the resulting fibers as capacitive energy storage devices. Equilibration of the hydrogel bio-template using K_2PtCl_6 solution mediates direct metal deposition. Nanostructure is dependent on the (bio)polymer molecule, crosslinking mechanism, and drying method. Such multi-functional electro-mechanical materials are envisioned to enable a broad range of applications such as sensors, photovoltaics, catalytic systems, fuel cells, and energy absorption.

Background

PROBLEM / MOTIVATION. Soldier load caused by device power requirements with batteries is excessive leading to operational fatigue and long-term health consequences. The formation of multi-functional capacitive textile fibers with high specific surface area and hierarchical porosity confers significant advantages for conductivity, mass transfer properties, reaction specificity, and strength and has been demonstrated with a direct reduction method [1], as well as on gelatin[2] and cellulose nanofiber templates.[3]

CHALLENGE / OBJECTIVE. Decrease Soldier load with multi-functional fiber-capacitors combining structural and energy storage mass. porous composite capacitive textile fibers comprised using biological molecules and carbon nanotubes for nanowire hierarchical assemblies. Objective nanowire fibers are envisioned for use capacitors, batteries, and sensors.

Materials & Methods

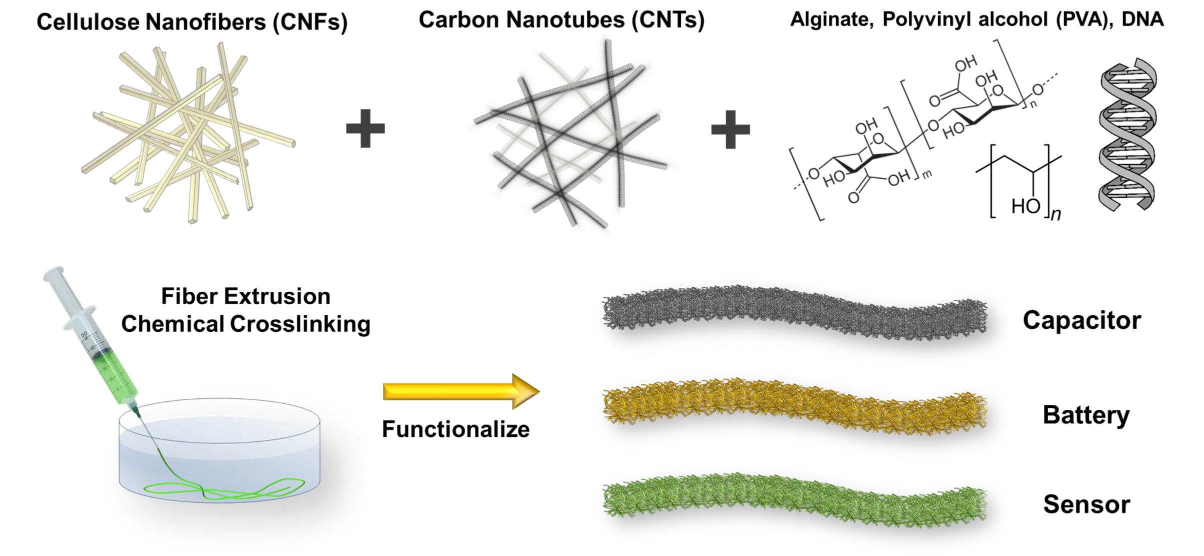

Figure 1. Biofiber synthesis scheme. Needle injection of CNT-biopolymer into crosslinking solution. Biopolymer solutions mixed at a 1:1 (w/w) with oxidized carbon nanotubes include cellulose nanofibers (CNF), polyvinyl alchohol (PVA), and deoxyribonucleic acid DNA). Cross linking solution consists of 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (EDC) and ethylenediamine as a linker molecule to form amide bond linkages between composite material components. Fiber functionalization to capacitor, battery, or sensor is achieved through tunable metallization.

Results

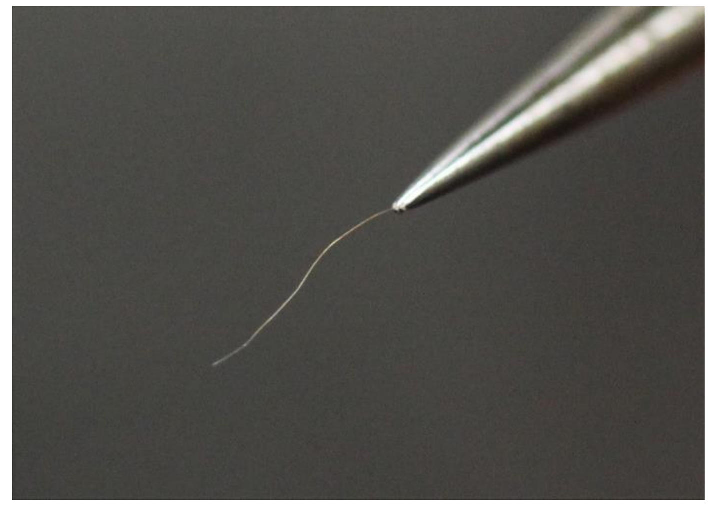

Figure 2. Photo of air-dried cellulose nanofiber hydrogel fiber.

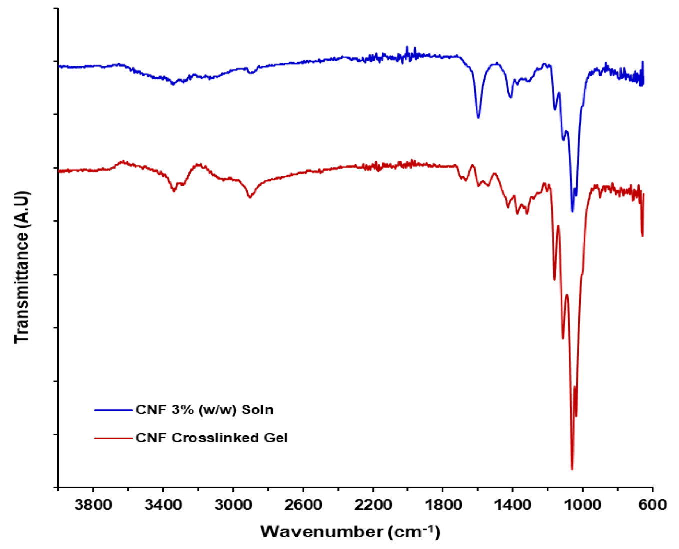

Figure 3. Fourier transform infrared (FTIR) spectra of 3% cellulose nanofiber (CNF) solution (blue) and EDC crosslinked CNF fiber (red).

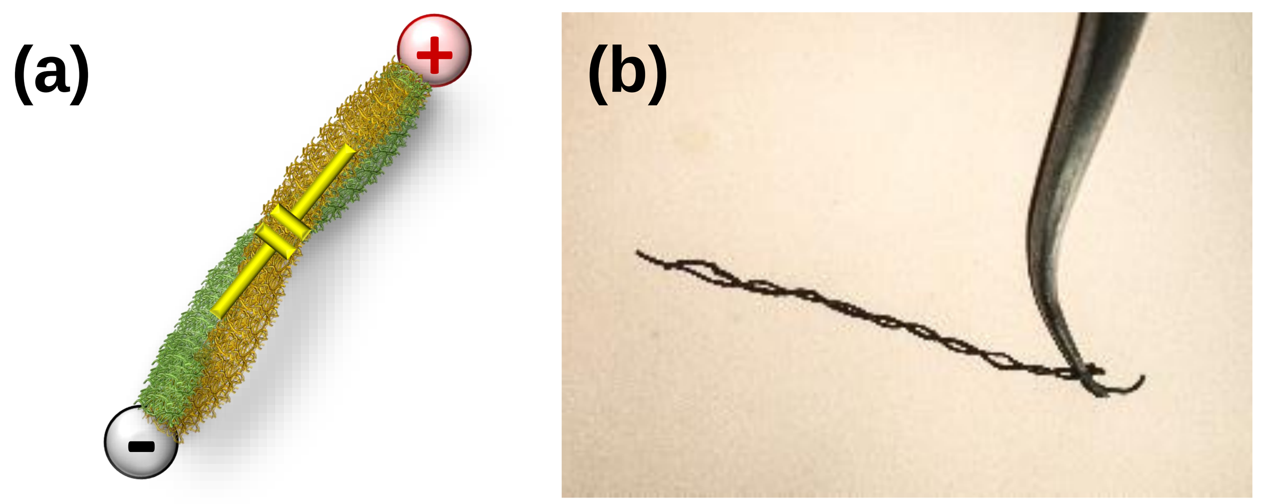

Figure 4. (a) Intertwined CNT-biopolymer multi-functional fibers serving as both textile fiber and capacitive energy storage material. (b) Intertwined CNT-alginate fibers precipitated from 10%, 1:1 (w/w) CNT:alginate solution extruded into 10 M $CaCl_2$.

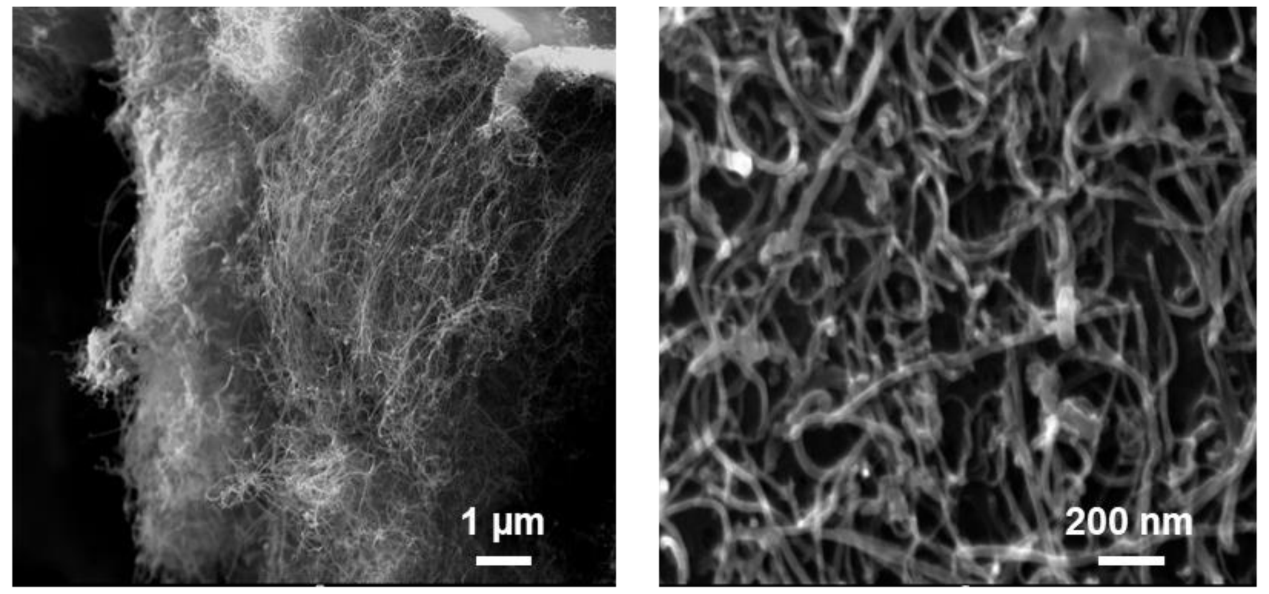

Figure 5. 3-D integrated CNT-biopolymer high surface area nano-architecture. Inter-penetrating CNT network upholds toughness, tensile strength, conductivity.

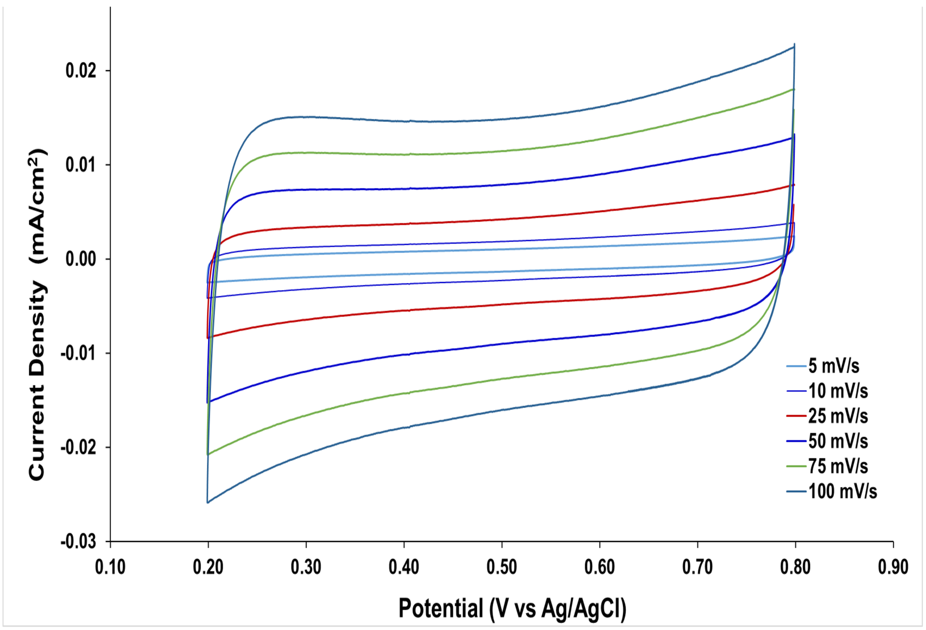

Figure 6. Cyclic voltammetry in 0.5 M KCl of CNT-PVA fiber serving as textile fiber and capacitive storage material. Specific capacitance of 11.4 mF/cm^2.

Figure 7. Expedient production, massive scalability, and cheap manufacture into any arbitrary geometry to include fibers, panels, aerogels, and conformal coatings.

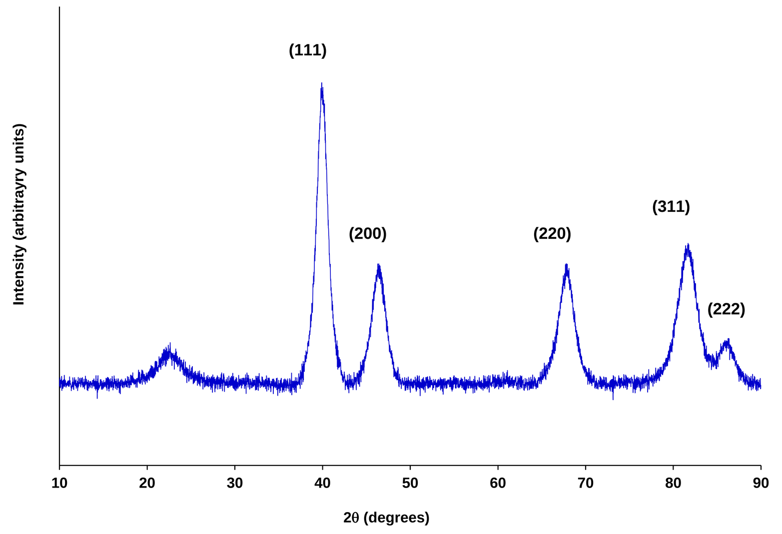

Figure 8. X-ray diffraction (XRD) spectra. Platinum peaks were indexed to Joint Committee on Powder Diffraction Standards (JCPDS) reference number 01-087-0640 for platinum.

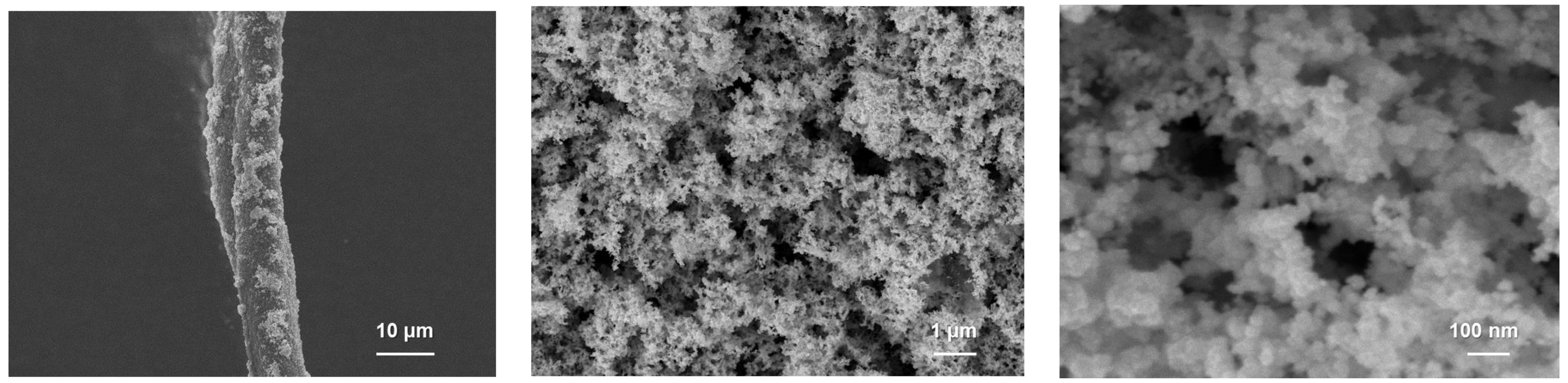

Figure 9. Scanning electron microscope images of cellulose nanofiber biotemplated fibers crosslinked with 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide hydrochloride (EDC) with a diamine linker. Air dried fibers were equilibrated in 0.5 M K_2PtCl_6 and reduced with 1 M $NaBH_4$.

Conclusions

The use of (bio)polymers such as cellulose nanofibers, polyvinyl alcohol, and DNA with carbon nanotubes to synthesize hierarchical, 3D porous multifunctional textile fibers for capacitive energy storage offers a route to achieve high specific surface area materials for a wide range of sensors, energy storage, and catalytic applications. Multi-functional capacitive textile fibers are envisioned to decrease overall Soldier load by combining the mass of uniform fibers and battery energy storage mass and provide tunable conductance, energy storage, mass transport, stiffness, and yield strength. Electro-mechanical testing suggests minimum objective performance metrics of 10-1000 µm diameter fibers with 582 m^2/g, and 11.4 mF/cm^2.

Future Work

References

[1] Burpo, F.J.*, Nagelli, E., Morris, L., McClure, J., Ryu, M., Palmer, J. Direct Solution-Based Reduction Synthesis of Au, Pd, and Pt Aerogels.*J. Mat. Res*. 2017, 32 (22), 4153.

[2] Burpo, F.J.,*, Mitropoulos, A., Nagelli, E., Ryu, M., Palmer, J. Gelatin Biotemplated Pt Aerogels. *MRS Advances*, 2018, 3(47-48), 2875.

[3] Burpo, F.J.*, Mitropoulos, A., Nagelli, E., Morris, L., McClure, J., Palmer, J., Ryu, M. Cellulose Nanofiber Biotemplated Palladium Aerogels. *Molecules.* 2018, *23*, 1405.

Acknowledgements

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