Electronic Supplementary Information

One-step Production of Continuous Supercapacitor Fibers for a Flexible Power Textile

Yang Hong, Xun-Liang Cheng, Ge-Jun Liu, Dong-Sheng Hong, Si-Si He, Bin-Jie Wang, Xue-Mei Sun, and Hui-Sheng Peng*

State Key Laboratory of Molecular Engineering of Polymers, Department of Macromolecular Science, and Laboratory of Advanced Materials, Fudan University, Shanghai 200438, China

Corresponding Author:

Hui-Sheng Peng, E-mail: penghs@fudan.edu.cn.

Experimental section

1. Characterization

The photographs were taken by a digital camera (Nikon, J1). Scanning electron microscopy (SEM) images and corresponding energy dispersive spectrometer mapping images were recorded using a field-emission scanning electron microscopy (Ultra 55, Zeiss), operated at 3 kV and 20 kV. X-ray diffraction analysis was conducted on an X-ray power diffractometer (Bruker, D8 ADVANCE) with filtered Cu Kα radiation. The mechanical properties were measured by an HY0350 Table-top Universal Testing Instrument. The viscosities of the gel electrolyte and electrode ink were measured using a NDJ-5S digital viscometer, Shanghai Sunny Hengping Scientific Instrument Co., LTD. The electrical resistance was measured by an Agilent 34401A digital multimeter.

All electrochemical measurements, including the cyclic voltammograms, galvanostatic charge-discharge curves, cycling performance measurements, and electrochemical impedance spectra were recorded by a CHI 660a electrochemical workstation and an Arbin electrochemical station (MSTAT-5 V/10 mA/16Ch). The size of all the supercapacitor fibers measured were set to be the same, typically 1.5 cm in length and ca. 300 μm in diameter. All measured supercapacitor fibers were fabricated under the same flow rate ratio between gel electrolyte and electrode ink at 500/100 (μL/min). The bending cyclic stability measurements of the supercapacitor fiber were performed by a linear motor-driven reciprocating machine with a speed of 100 cycles per min. For a typical bending test, two ends of the supercapacitor fiber with length of 8 cm were first fixed and then bent into 150^{o} bending angle.

2. Calculation of electrochemical parameters of supercapacitor fibers

The volumetric capacitance (C_v) of the whole supercapacitor fiber was calculated by the following equation:

$$C_v = \frac{I \times \Delta t}{V \times \Delta U}$$

where I, Δt, V, and ΔU are discharge current, discharge time, volume of whole supercapacitor fiber and voltage window, respectively.

The volume of the supercapacitor fiber was calculated by assuming it as a cylinder. So the volume can be obtained by the following equation:

$$V = A \times L = \pi \times R^2 \times L$$

where A is the cross-sectional area of the supercapacitor fiber, R is the radius of the supercapacitor fiber, and L is the length of the supercapacitor fiber.

The volumetric energy density (E_V) and volumetric power density (P_V) can be calculated from the equations:

$$E_V = C_V \times \Delta U^2/2 \times 3600$$

$$P_V = E_V \times 3600/\Delta t.$$

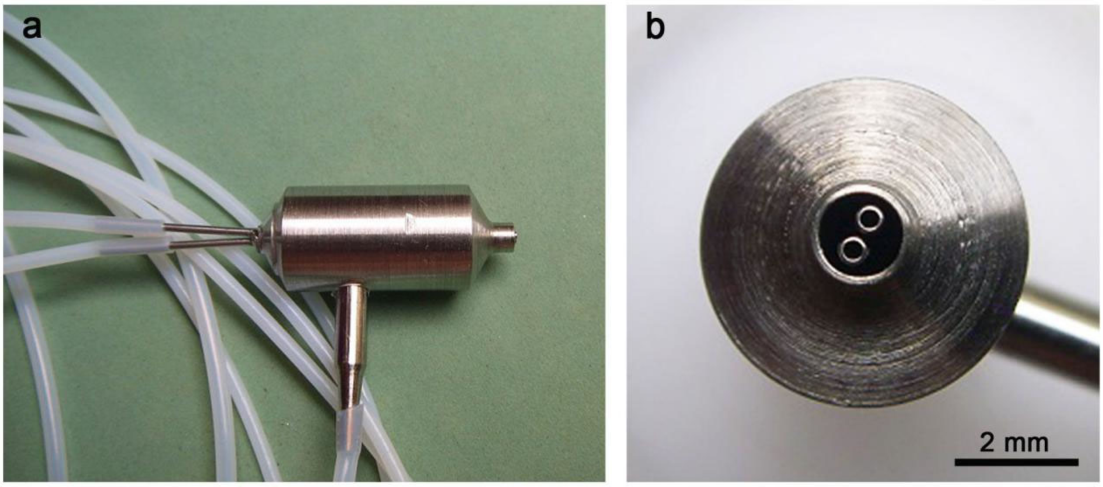

Figure S1. Photographs of a custom-designed multichannel spinneret by side view (**a**) and its nozzle by top view (**b**).

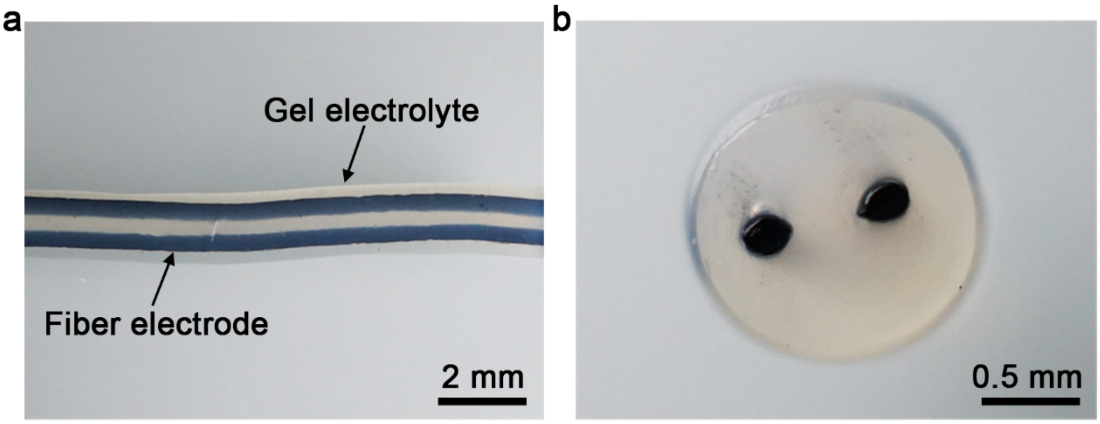

Figure S2. Photographs of a freshly collected supercapacitor fiber by side (**a**) and cross-sectional views (**b**).

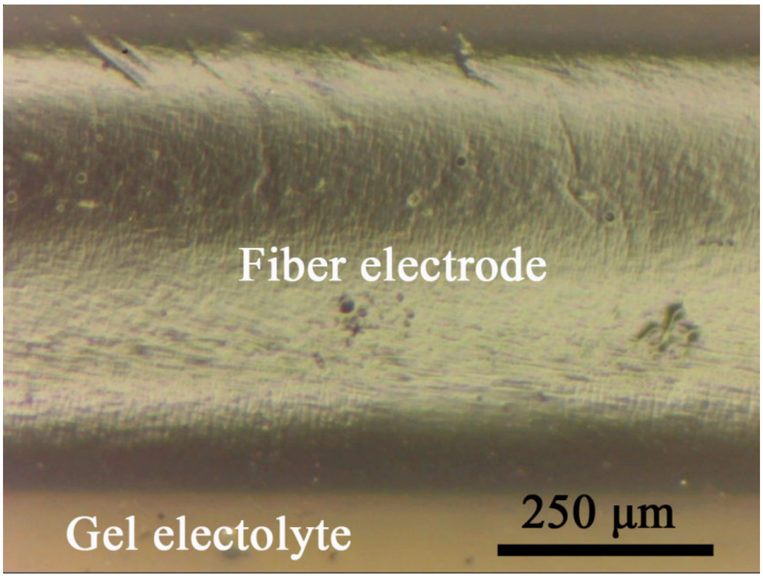

Figure S3. Optical micrograph of a single fiber electrode in the freshly collected supercapacitor fiber.

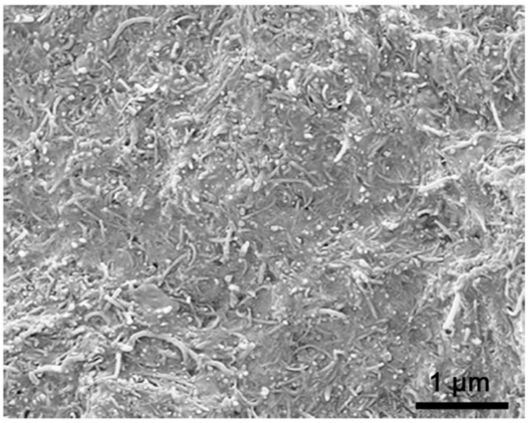

Figure S4. SEM image of an electrode in a supercapacitor fiber at high magnification.

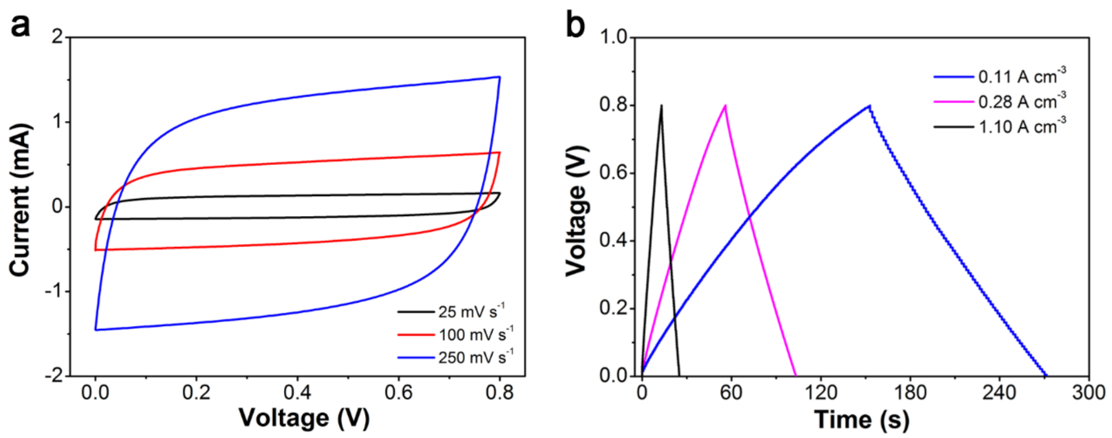

Figure S5. (**a**) Cyclic voltammograms of the supercapacitor fibers made from PEDOT:PSS/CNT electrode ink at different scanning rates. (**b**) Galvanostatic charge-discharge curves at different current densities. The length of the supercapacitor fiber for cyclic test was 1.5 cm.

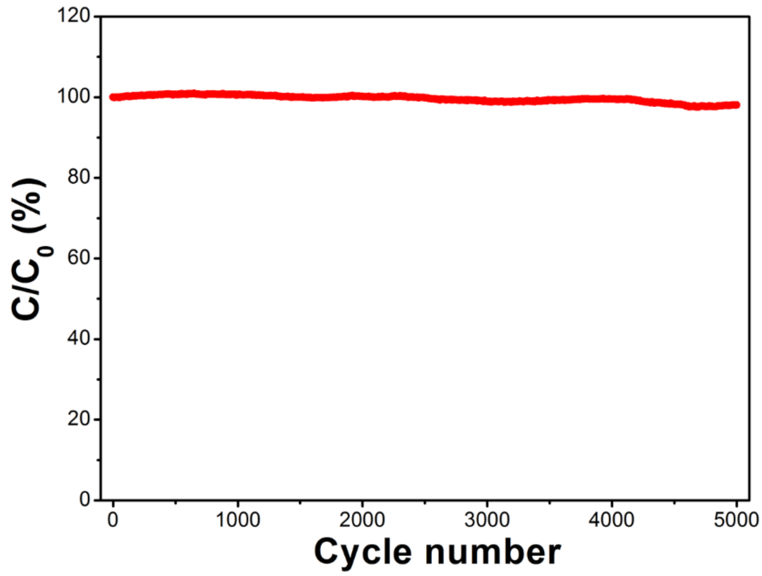

Figure S6. Cycling performance of a supercapacitor fiber using a PEDOT:PSS/CNT electrode ink measured at a current of 0.4 mA. The length of the supercapacitor fiber for cyclic test was 1.5 cm.

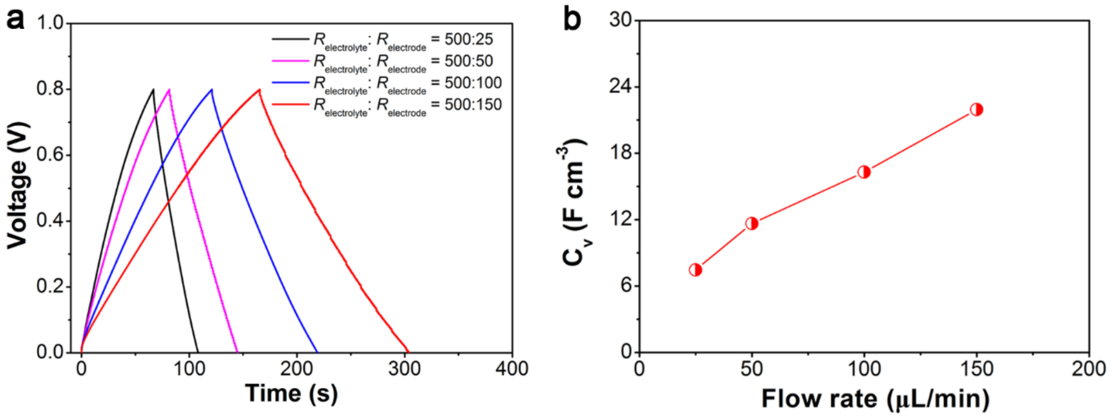

Figure S7. (**a**) Galvanostatic charge-discharge curves of the supercapacitor fibers produced under different flow rates between electrode ink and gel electrolyte. (**b**) Dependence of specific capacitance on the flow rate of electrode ink while fixing the rate of gel electrolyte at 500 μm/min.

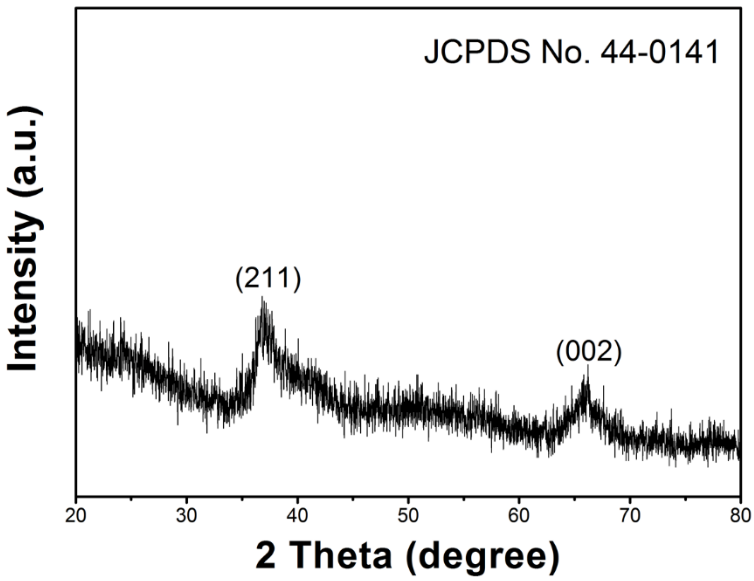

Figure S8. XRD pattern of MnO_2 nanoparticles.

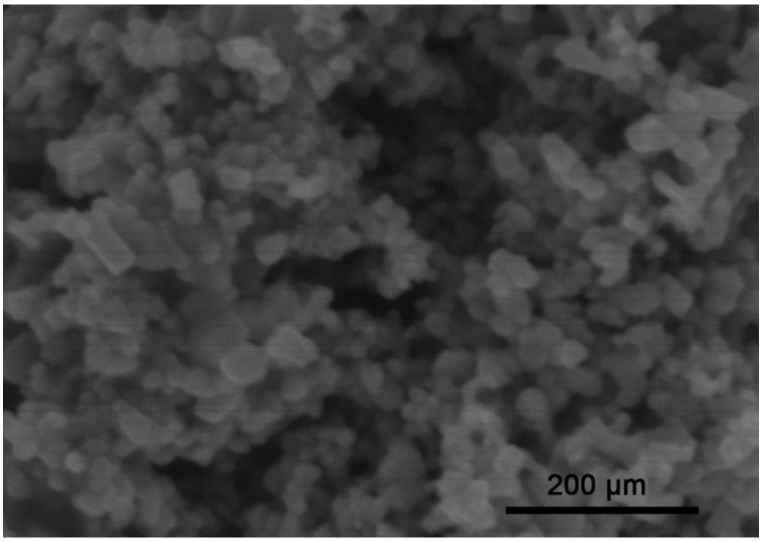

Figure S9. SEM image of MnO_2 nanoparticles.

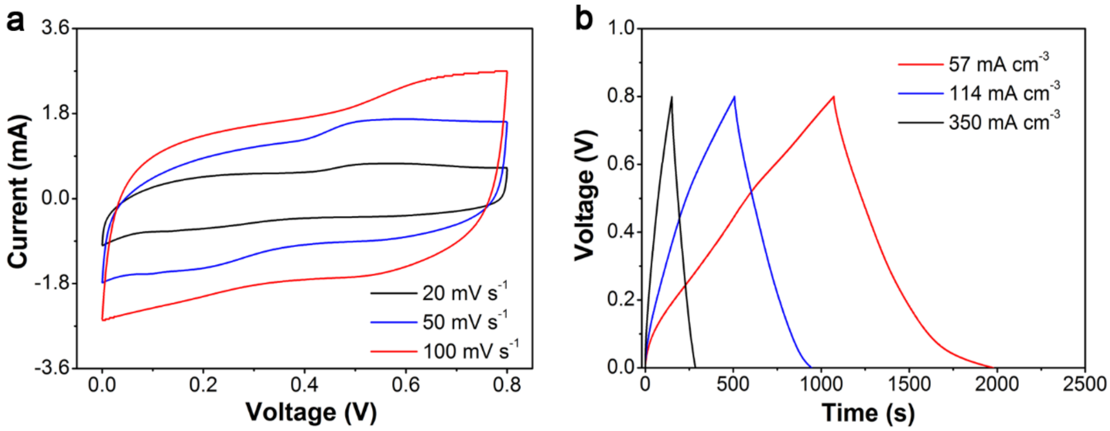

Figure S10. Electrochemical performance of a supercapacitor fiber made from an electrode ink containing PEDOT:PSS, CNT and MnO_2. (**a**) Cyclic voltammograms at different scanning rates. (**b**) Galvanostatic charge-discharge curves at different current densities.

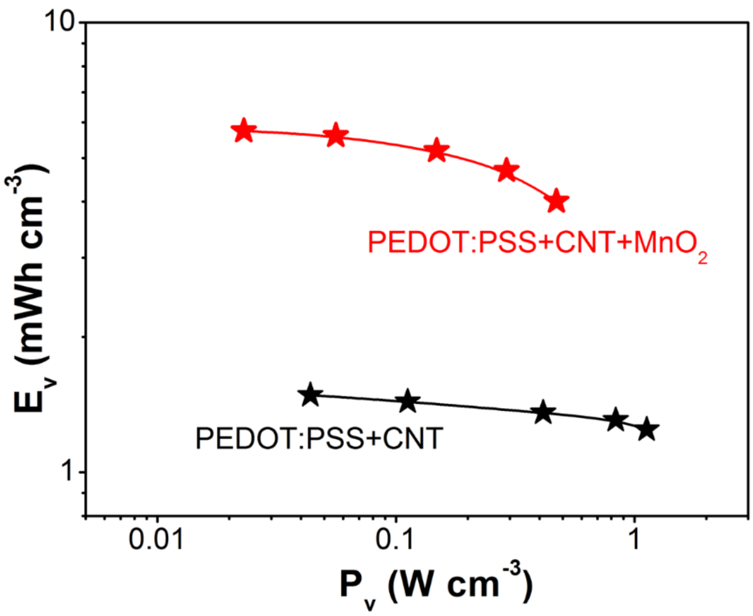

Figure S11. Comparison of the volumetric energy and power densities of two wet-spun supercapacitor fibers based on the electrodes of PEDOT:PSS/CNT/MnO_2 and PEDOT:PSS/CNT.

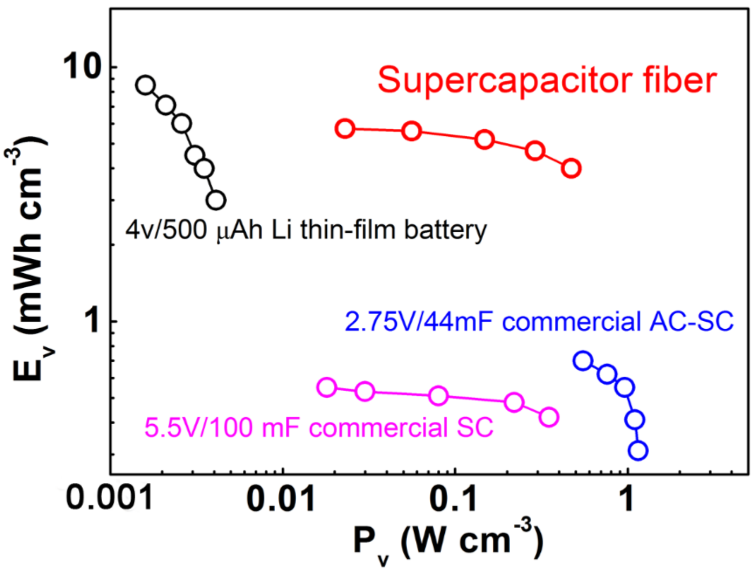

Figure S12. Comparison of the volumetric energy and power densities of a PEDOT:PSS/CNT/MnO_2 based supercapacitor fiber with commercial energy storage devices. Here EC represents electrochemical capacitor.[S1,2]

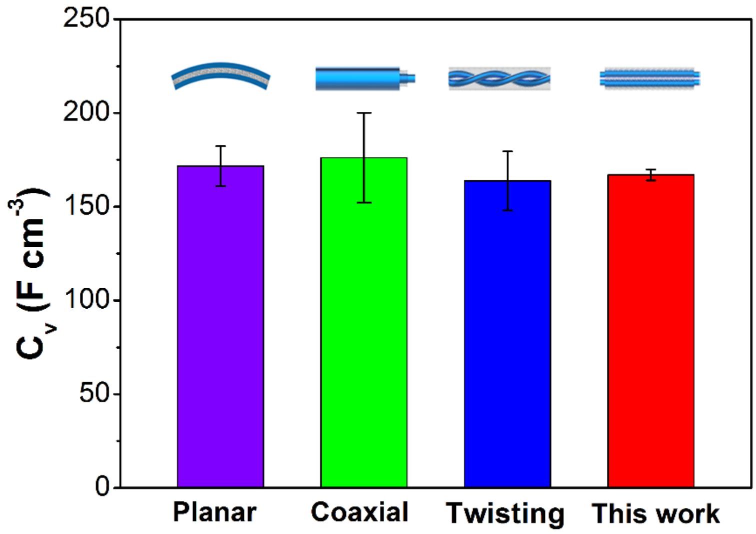

Figure S13. Comparision of the specific capacitance of four devices with different configurations. The weight of the PEDOT:PSS/CNT electrode in each supercapacitor was the same. For each supercapacitor, 20 samples were tested.

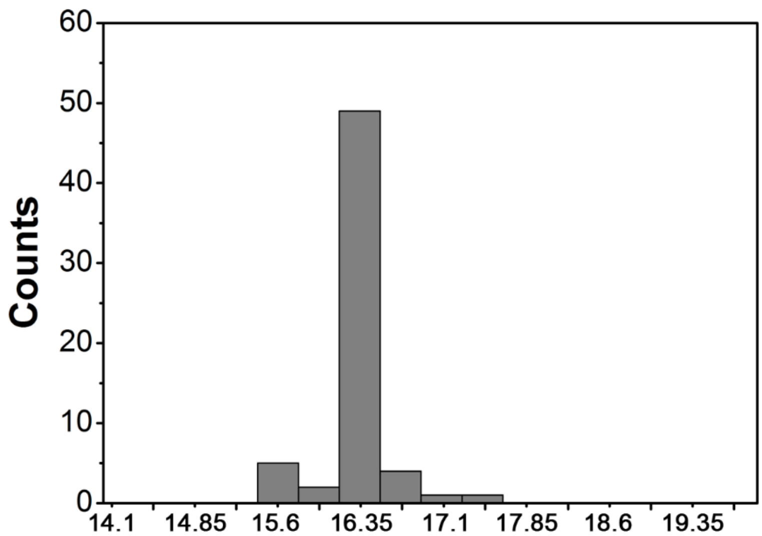

Figure S14. Histogram of the specific capacitance of 62 wet-spun supercapacitor fibers (based on PEDOT:PSS/CNT electrode ink) with the same length of 1.5 cm under the same fabrication condition.

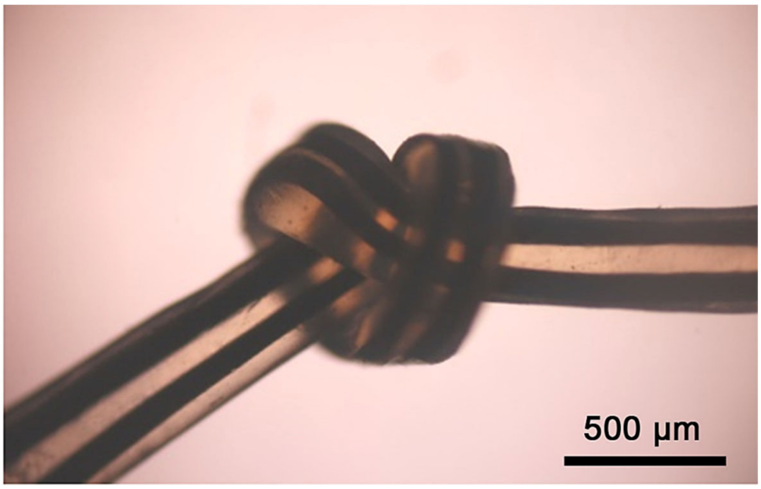

Figure S15. An optical micrograph of a knoted supercapacitor fiber.

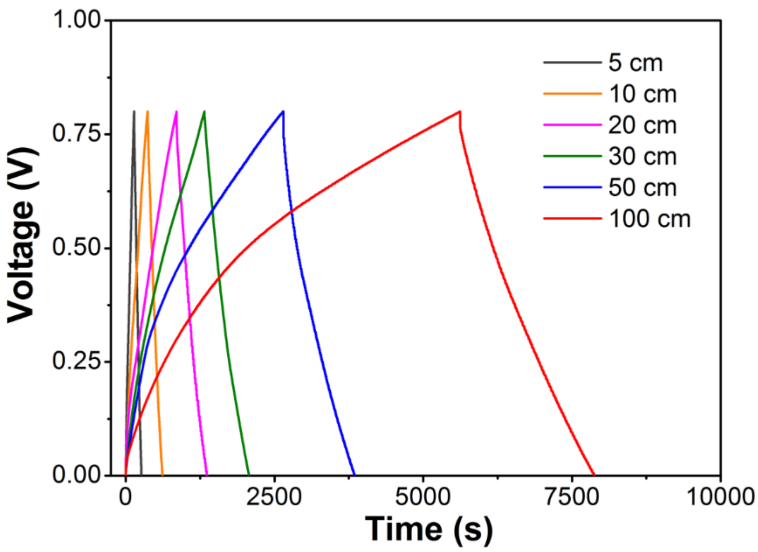

Figure S16. Galvanostatic charge-discharge curves of the PEDOT:PSS/CNT/Ag NW based supercapacitor fiber with increasing lengths from 5 to 100 cm. The supercapacitor fibers were measured at a constant current of 0.32 mA.

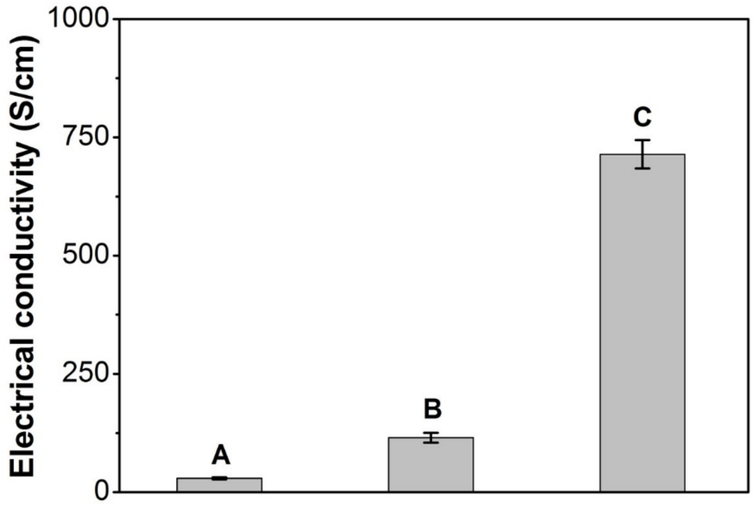

Figure S17. Electrical conductivities of electrode fibers made from different electrode inks. A: PEDOT:PSS, B: PEDOT:PSS+CNT, and C: PEDOT:PSS+CNT+Ag NW. Here CNT and NW represent carbon nanotube and nanowire, respectively. For each supercapacitor, 20 samples were tested.

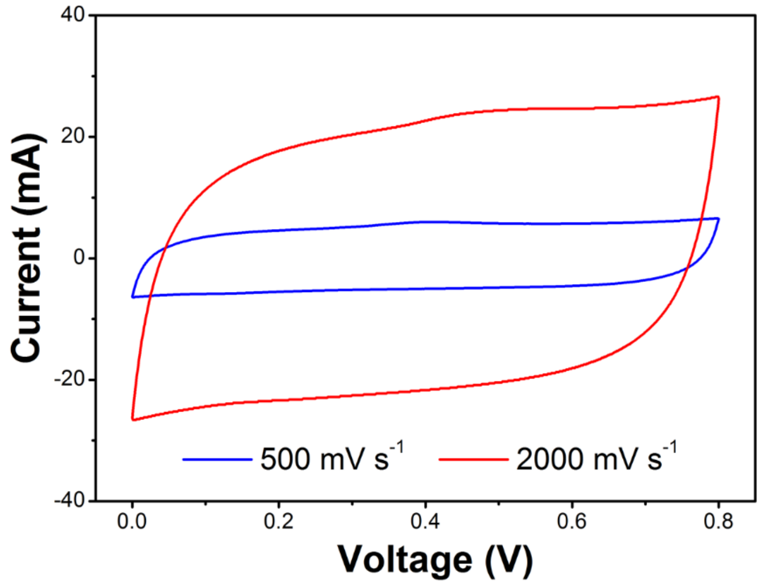

Figure S18. Cyclic voltammograms of the supercapacitor fiber based on the electrode ink of PEDOT:PSS/CNT/Ag NW.

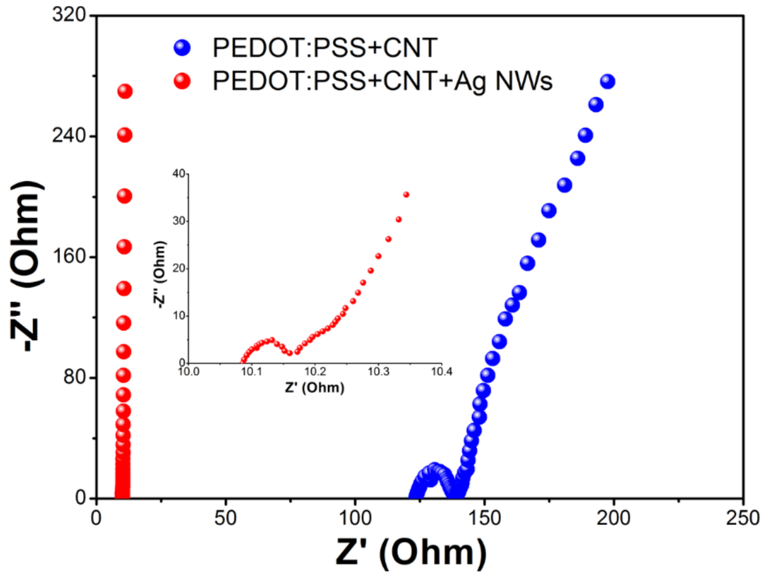

Figure S19. Electrochemical impedance spectra of two supercapacitor fibers made from different electrode inks of PEDOT:PSS/CNT/Ag NW and PEDOT:PSS/CNT.

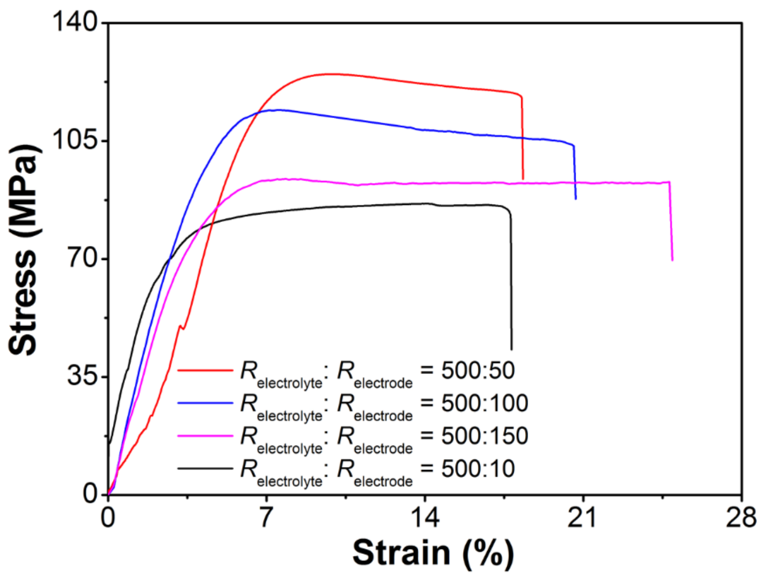

Figure S20. Stress-strain curves of the wet-spun supercapacitor fibers fabricated by different flow rates between electrode ink and gel electrolyte.

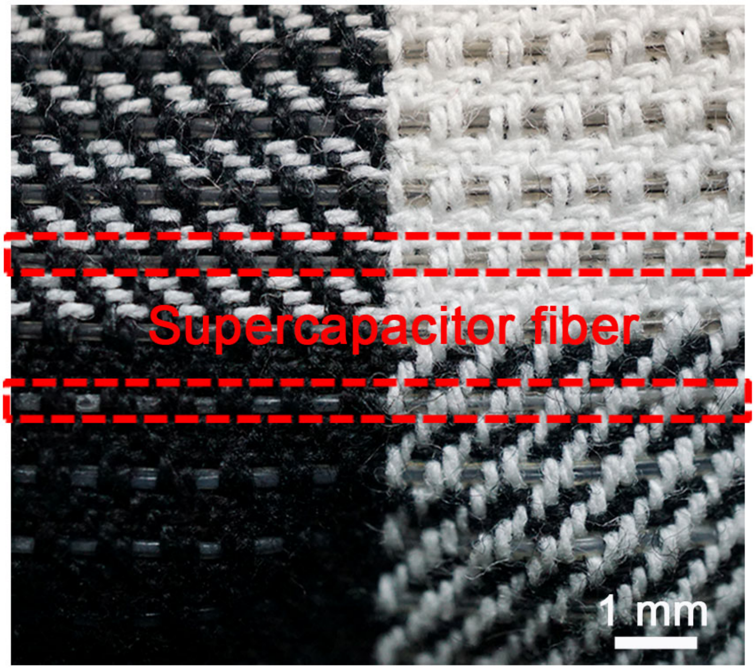

Figure S21. Photograph of a supercapacitor scarf.

Figure S22. Photograph of the supercapacitor scarf.

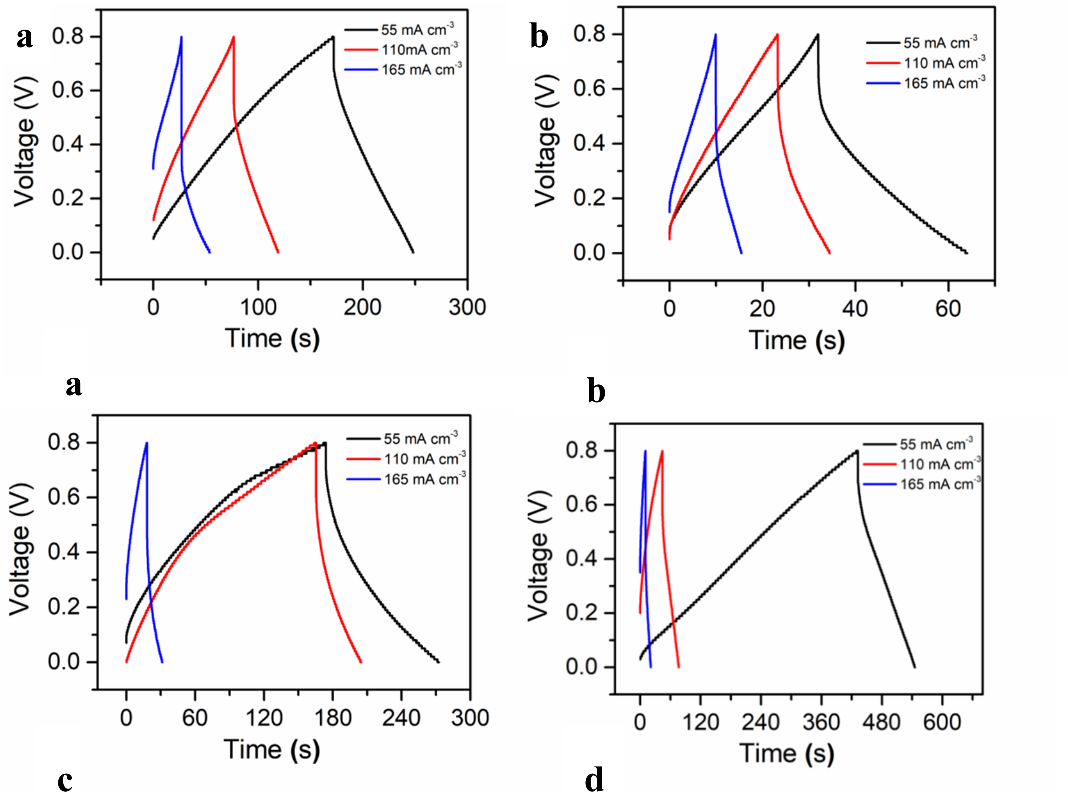

Figure S23. (a), (b), (c), (d) are the rate performance of the fiber-shaped supercapacitors with different lengths of 5, 10, 15, and 20 cm respectively, which are made from an electrode ink containing PEDOT:PSS, CNT and Ag nanowire.

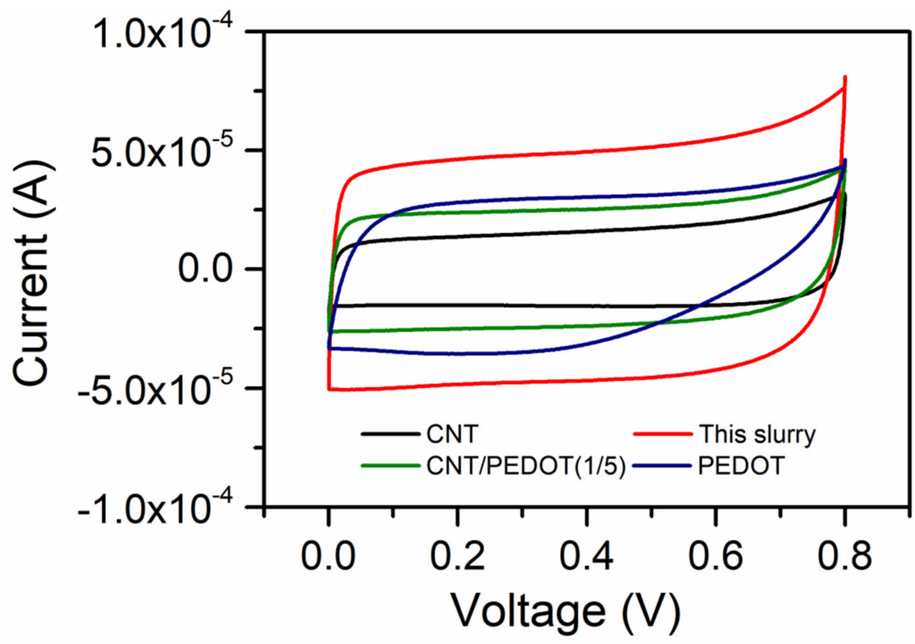

Figure S24. Cyclic voltammograms of the supercapacitor fiber using different ratios of PEDOT:PSS /CNT at 10 mV/s.

References for the Supporting Information

[S1] J. A. Lee, M. K. Shin, S. H. Kim, H. U. Cho, G. M. Spinks, G. G. Wallace, M. D. Lima, X. Lepró, M. E. Kozlov, R. H. Baughman, S. J. Kim, *Nat. Commun.* **2013**, *4*, 1970.

[S2] Z. S. Wu, K. Parvez, X. Feng, K. Müllen, *Nat. Commun.* **2013**, *4*, 2487.