SUPPORTING INFORMATION:

Electrospun Metal Nanofiber Webs as High Performance Transparent Electrode

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Experimental Procedure

Electrospinning. PVA (Mw = 42 000 g mol^{-1}, Aldrich) was dissolved in distilled water at a concentration of 10 wt%. Copper acetate (Aldrich) was then added into the solution at a concentration of 10 wt%. The mixture was stirred and ultrasonically agitated for 24 h to form homogeneous solutions for electrospinning. The PVA/$CuAc_2$ blended solution was loaded in a 1 mL plastic syringe attached to a syringe pump (KDS200, KD Scientific Inc.) which provided a steady solution flow rate of 0.2 mL/h during electrospinning. A high-voltage power supply (Gamma High Voltage Research) was employed to generate a high potential of 15 kV to a 21 gauge blunt end syringe needle. The electrospun nanofibers were collected onto a glass slide on grounded aluminium foil, which were horizontally and perpendicularly placed 12 cm away from the spinneret. The nanofiber-coated glass slides were heated in air at 500^{o}C for 2 hours at a heating rate of 5 °C/min. Subsequent annealing occurred at 300^{o}C in an H_2 atmosphere for half an hour in a tube furnace, with a heating rate of 2^{o}C/min. The H_2 gas pressure and flow rate were 40 Torr and 200 sccm/min, respectively. After hydrogen reduction, transparent Cu nanofiber thin films were fabricated on glass substrates.

Solar Cells. Poly-3-hexylthiophene (P3HT):[6,6]-phenyl-C61-butyric acid (PCBM) solar cells[34] were fabricated using routine methods while taking care to minimize unnecessary air exposure to the Cu nanofiber substrates. Briefly, a 50 nm layer of PEDOT:PSS (Clevios PH 500) was formed by depositing a single drop on a sample spinning at 4000 rpm in air. The sample was then transferred to a nitrogen filled glove box and annealed at 110 ºC for 10 minutes. The active layer (P3HT:PCBM 1:1 weight ratio, 25 mg/mL in dichlorobenzene, film thickness: ~240 nm) and metal electrode (7 nm Ca / 200 nm Al) deposition and device testing were performed inside a nitrogen glove box.

Characterizations. Nanofibers were characterized by means of SEM (FEI XL30 Sirion, with an accelerating voltage of 15 kV), TEM and EDS (FEI Tecnai G2 F20 X-TWIN with EDS, operating at an accelerating voltage of 200 kV), wide-angle X-ray analysis (PANalytical X'Pert PRO x-ray diffraction system). Standard hemispherical measurements were carried out for transmittance measurement with an integrating sphere (Newport), a xenon lamp coupled with a monochromator. An identical glass substrate is used as the reference in the measurement. The electrical properties measurement of Cu fiber films were carried out on an Agilent B1500A semiconductor device analyzer. The sheet resistances were measured by a four-terminal configuration to remove the contact resistances. Each stripe-shaped contact was made by conductive silver paint (Silver Print II, GC Electronics), which has a typical ohmic contact resistance less than 1 ohm. To obtain the sheet resistance, four-terminal I-V measurements were conducted by flowing a known current through the two outermost contacts and monitoring the voltage drop between the two inner contacts.

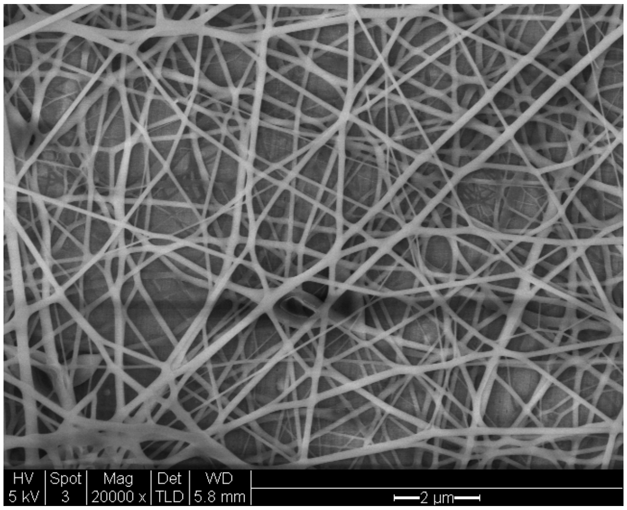


Figure S1. Scanning electron microscopy (SEM) image of poly polyvinyl acetate (PVA)/copper acetate ($CuAc_2$) precursor nanofibers.

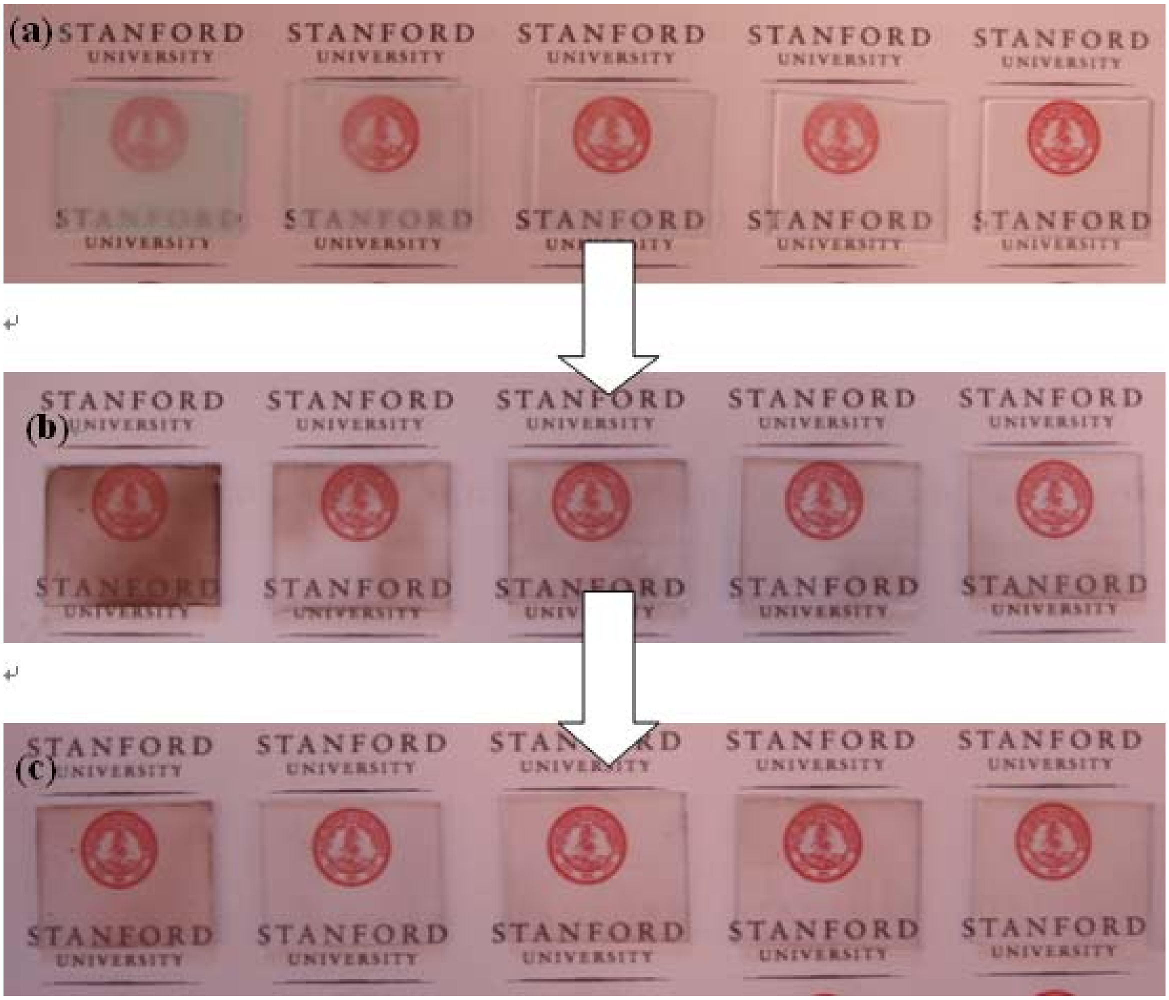


Figure S2. Digital photos show color changes of samples. (a) PVA/CuAc$_2$ precursor nanofibers (blue), (b) CuO nanofibers, fabricated by heating precursor nanofibers at 500^{o}C in air (brown), (c) Cu nanofibers by reducing of CuO nanofibers (red).

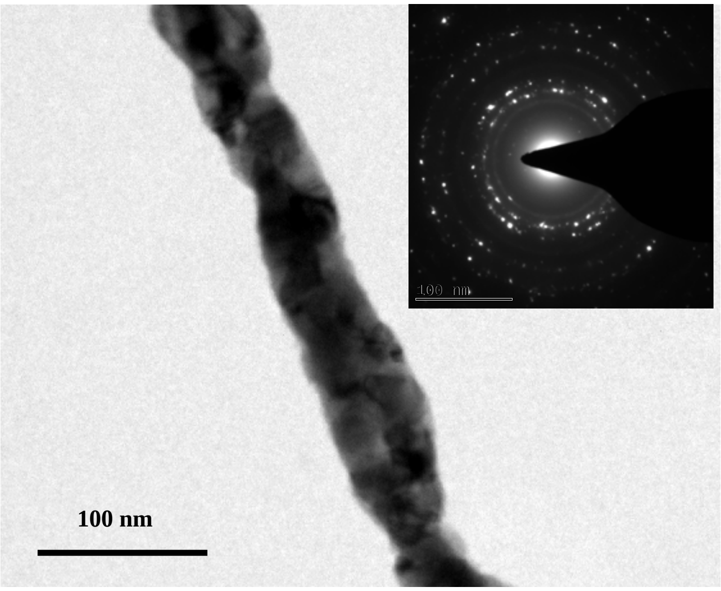
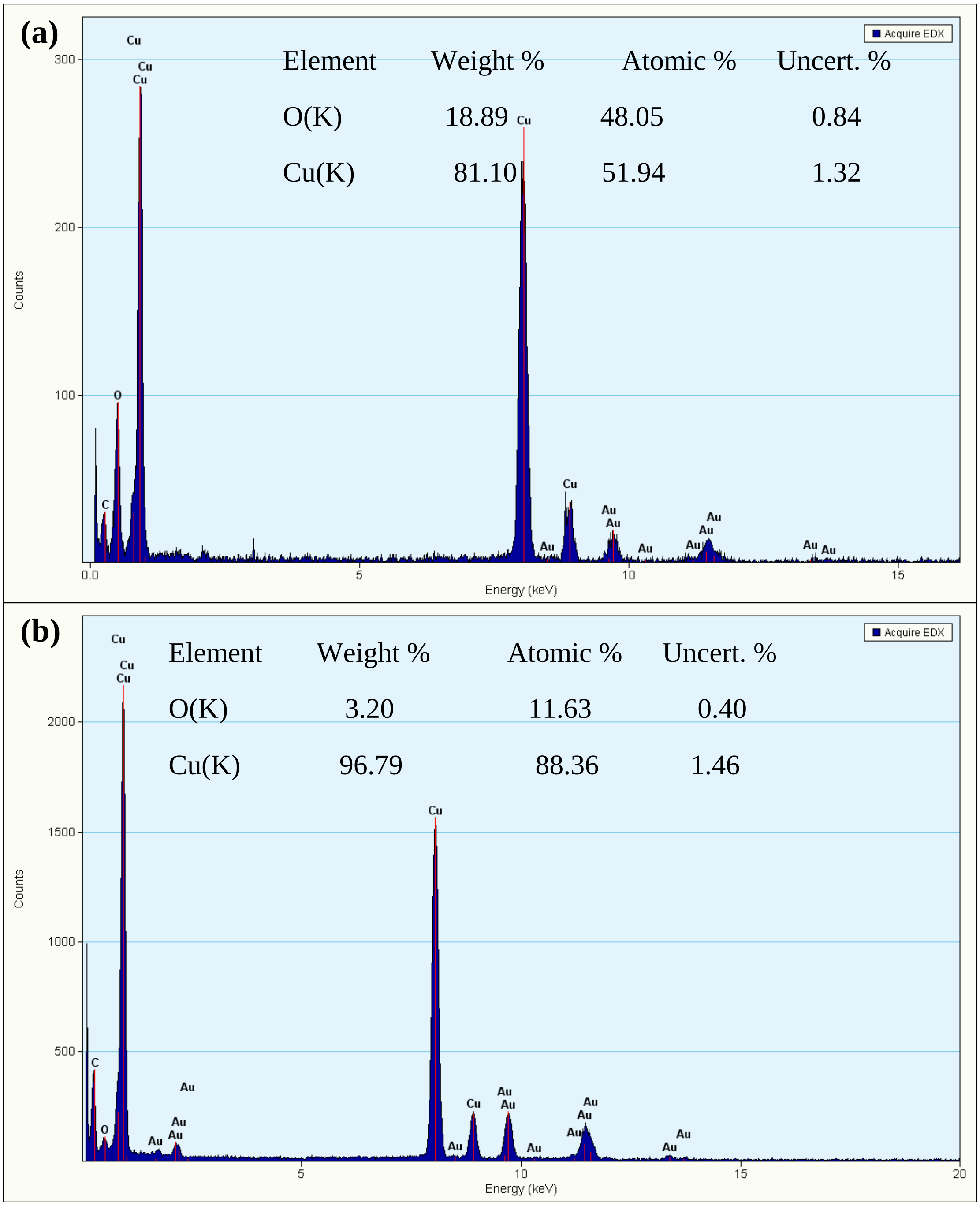


Figure S3. Transmission electron microscopy (TEM) image of Cu nanofibers. Inset: corresponding selected-area electron diffraction (SAED) pattern, showing polycrystalline structure of synthesized Cu nanofibers.



(a)

Element	Weight %	Atomic %	Uncert. %
O(K)	18.89	48.05	0.84
Cu(K)	81.10	51.94	1.32

(b)

Element	Weight %	Atomic %	Uncert. %
O(K)	3.20	11.63	0.40
Cu(K)	96.79	88.36	1.46

Figure S4. Energy dispersed electron spectroscopy (EDS) spectra of (a) CuO nanofibers, (b) Cu nanofibers. Au signal comes from the Au TEM grids we used. A significant O peak is observed in CuO nanofibers (a), while there is little O in Cu nanofibers (b).

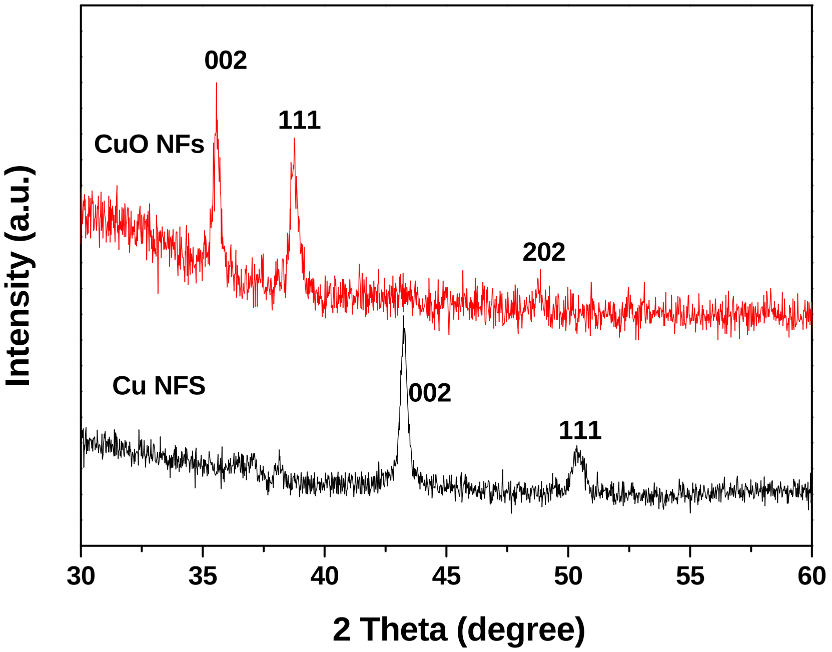


Figure S5. X-ray diffraction (XRD) pattern of CuO nanofibers and Cu nanofibers.

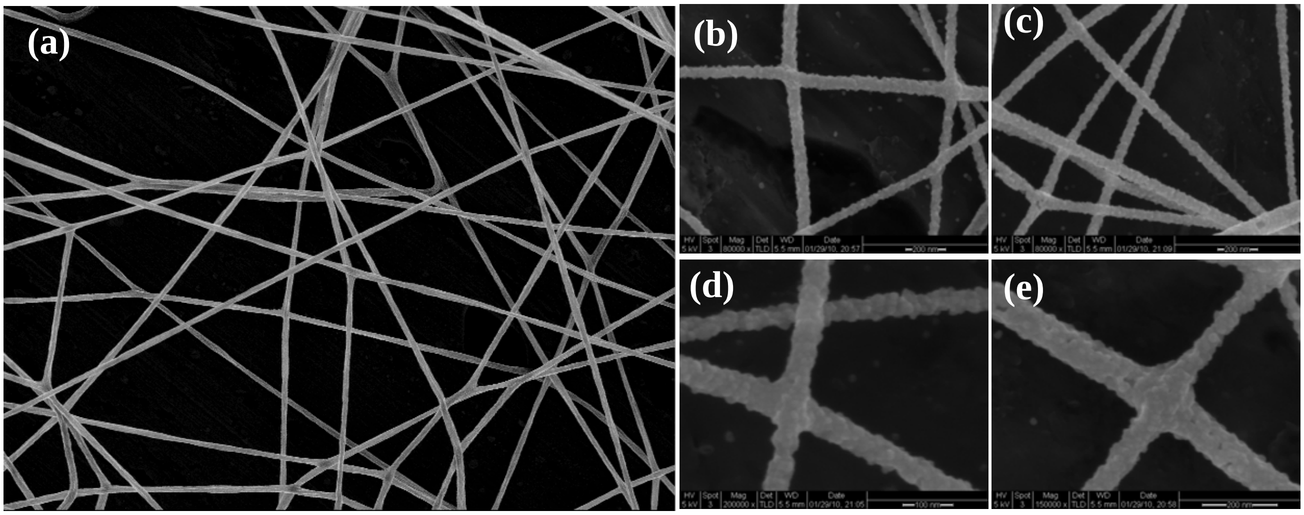


Figure S6. SEM image of Cu nanofiber webs with low (a) and high (b-e) magnifications, showing fused junctions between nanofibers.

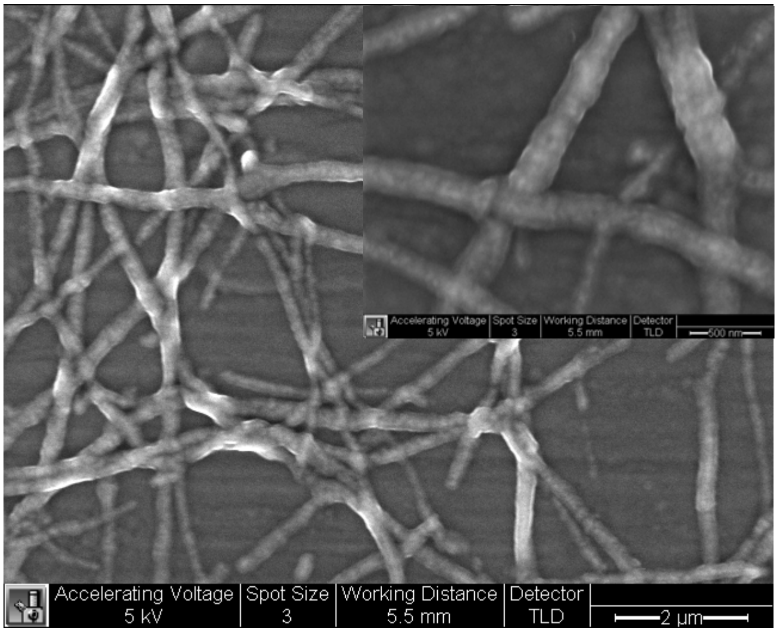


Figure S7. SEM image of Cu nanofibers after spin coating of 50 nm thick PEDOT:PSS and stored for 7 days.

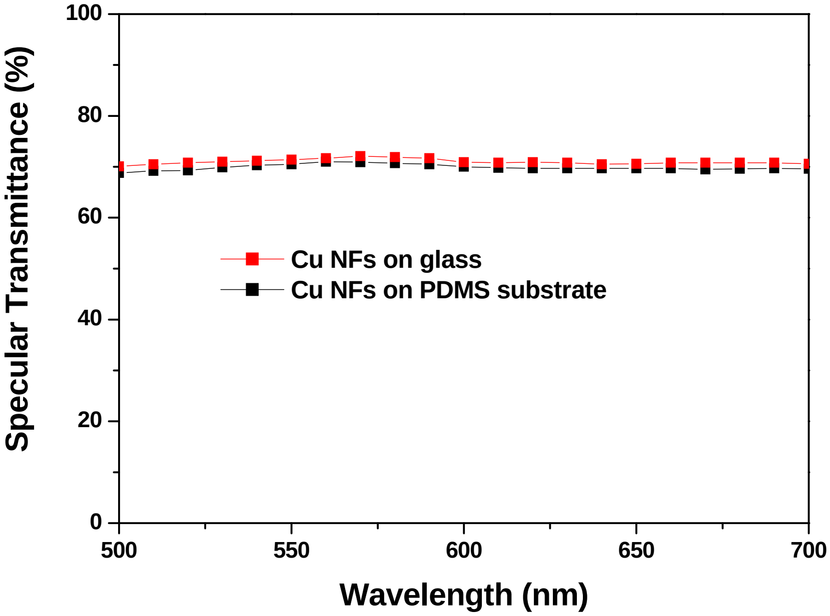


Figure S8. Specular transmittance of Cu nanofiber network on glass and PDMS substrates. The sheet resistance is 9.0 Ohm/sq and 9.3 Ohm/sq for each sample.