

Supplemental information

Wearable textile biofuel cells for powering electronics

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Experimental section

Printed Electrodes on Textiles

To fabricate textile BFCs, different textures of textiles were examined for screen-printing electrodes, including T-shirt (cotton), care label (polyester), GORE-TEX, socks (mixture), elastic band (Jockey®). (**Fig. S1**) A hydrophobic spray (Scotchguard®) was used to create a water resistant layer to avoid water spread into the textiles for electrochemical measurements. The electrodes were screen-printed on treated textiles by using an MPM-SPM semi-automatic screen printer (Speedline Technologies, Franklin, MA). A conductive carbon ink (E3449, Ercon Inc, Wareham, MA) and silver/silver chloride ink (124-36, Creative Materials, MA) were used for printing the electrode and contacts, respectively. The effective electrode area for both anode and cathode is 1.5 mm × 3 mm. The printed textile was cured at 95 °C for 10 min after each screen printing.

Preparation of Textile BFCs

For modification of bioanode, 0.1 M TTF·TCNQ (Sigma-Aldrich) suspension was prepared in methanol and sonicated for 2 h, and then mixed with a 5 mg/mL CNT ethanol solution in the ratio of 1:4 (v/v). After sonication for another 30 min, a 6 µL aliquot of the mixture was drop-cast on one of the electrode printed on care label. Lactate oxidase (LOx, Toyobo Inc, Japan, 101 U/mg, 40 mg/mL) was prepared with BSA (10 mg/mL) in 0.1 M phosphate buffer. The enzyme solution was cross-linked by glutaraldehyde (0.25%) and 3 µL of the enzyme solution were drop-casted on the electrode. After air dried, the electrode was coated further with a 2 µL chitosan solution (1% in 1M acetic acid). The cathode was modified with 15 µL of a 10 mg/mL Pt black powder (Sigma-Aldrich) aqueous solution for oxygen reduction. The electrode was covered with 1 µL Nafion (5 %, Fluka).

Electrochemical measurements

The anode and cathode of the textile BFC were connected through stainless steel wires with a potentiostat (CH Instrument 1232). *In vitro* measurements were conducted in 0.1 M phosphate buffer containing lactate fuel. Polarization curves were recorded by applying linear sweep voltammetry with a scan rate of 1 mV/s. Stability tests were conducted every hour for up to 6 h, while the textile BFCs were stored under ambient conditions between each measurement. For *in vitro* bending/stretching studies of the textile BFCs, the care label BFCs were attached to the headband (Nike) by using Velcro. The headband was stretched for 40% and bended at 270° up to 100 times and the performance of the textile BFC was examined after 20, 40, 60, 80 and 100 such iterations.

Electronic Integration

We employ a BQ25504 boost converter integrated circuit (Texas Instrumental, Dallas, TX) to step-up the voltage to a higher level by charging an energy-buffering capacitor. A schematic of the resulting printed circuit board (PCB), fabricated as a 2-layer board on 1.6 mm FR-4 (Advanced Circuits, Aurora, CO), is shown in **Fig. S2**. When the energy buffering capacitor reaches a voltage of 3.2 V, the output switch is enabled and power is delivered to the load. Since the instantaneous load power is typically greater than the power coming from the BFC, the capacitor voltage drops during load operation. When the voltage drops to 2.4 V, the output switch is disabled and the load is shut-off. At this point, the capacitor voltage begins to slowly replenish based on incoming energy harvested by the BFC.

To increase the absolute amount of power available under *in vivo* conditions, four BFCs were electrically connected in parallel. The board requires an initial power of 10 μ W to charge the capacitor, and measures less than $2 \times 5 \text{cm}^2$, which is small enough to be implemented in the headband or wristband. Excluding the test points and different load options on the PCB board can enable a much smaller overall size of $2 \times 2.5 \text{cm}^2$.

Supplementary Figures:

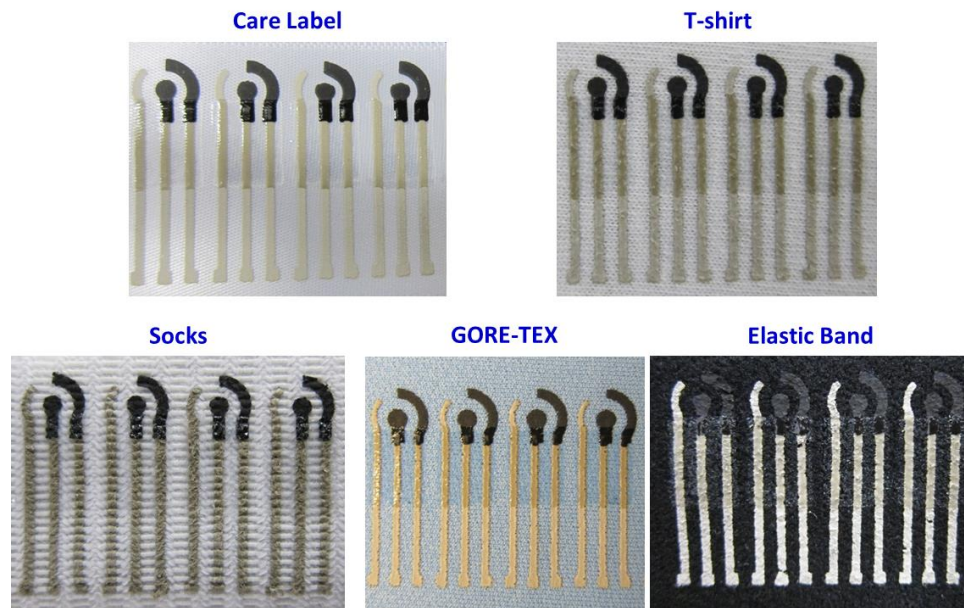


Figure S1. Screen-Printing on five different textiles

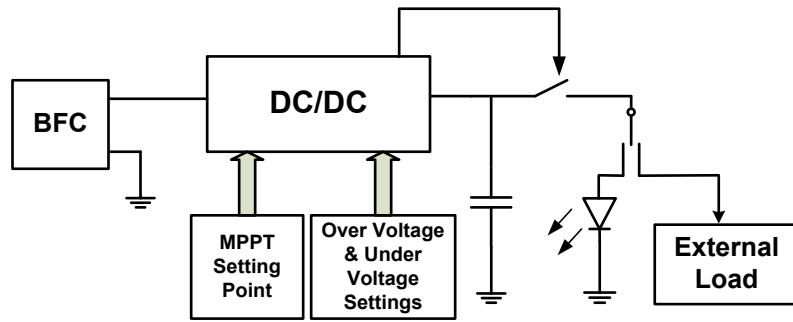


Figure S2. Simplified diagram of the energy harvesting PCB board