Electronic Supporting Information (ESI)

Super Soft Conductor Based on Liquid Metal/Cotton Composite

Shuai He,*[a] Caixia Zhou,[a] Hualin Chen,[a] Xingli Liu,[a] Hui Li,[a] Wenming Ma,[a] Xin Su*[b] and Tao Han[c]

[a] College of Chemistry and Environmental Protection Engineering, Southwest Minzu University, Chengdu 610041, China

[b] Polymer Research Institute, State Key Laboratory of Polymer Materials Engineering, Sichuan University, Chengdu 610065, China

[c] College of Chemistry and Life Science, Institute of Functional Molecules, Chengdu Normal University, Chengdu 611130, China

*Corresponding Authors (E-mail: heshuaifish@126.com (S. He); xinsu@scu.edu.cn (X. Su))

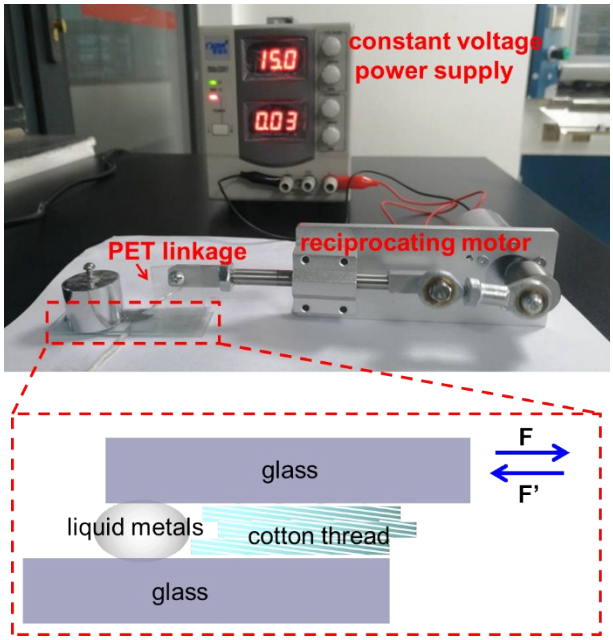

Fig. S1 The fabrication process of conductors based on liquid metal/cotton composites.

The upper glass sheet moved perpendicular to the cotton thread by a reciprocating motor (feed length = 10 mm). The speed and number of rubbing treatment were regulated by the constant voltage power supply. A reciprocating motion was treated as rubbing treatment once. The pressure applied was controlled by different weight on the upper glass sheet (75×25 mm).

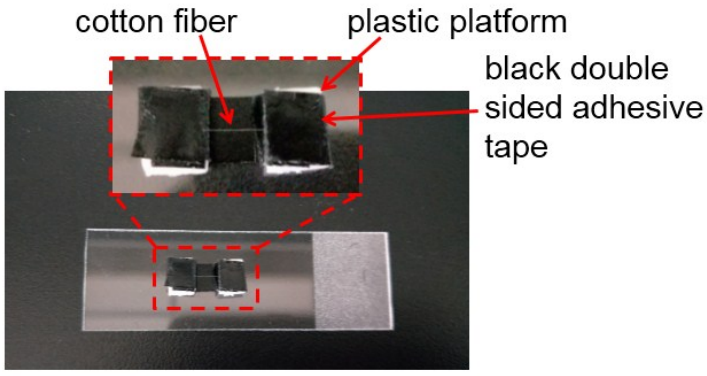

Fig. S2 The platform of the fiber fixation for microscopic observation.

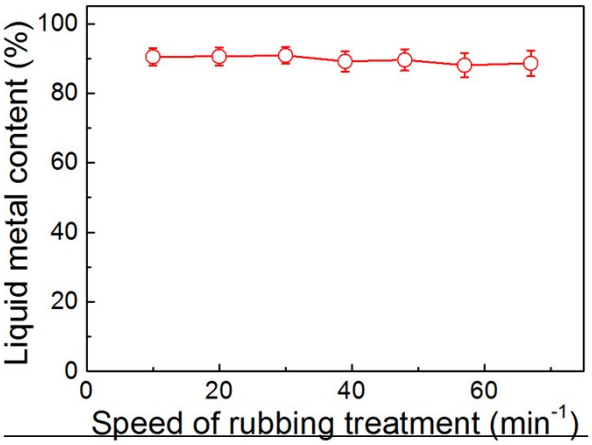

Fig. S3 Effect of speed of rubbing treatment on the liquid metal content of the conductor, and cotton thread with a diameter of 2.24±0.42 mm was used during the test (number: 50 times, pressure: 530 Pa).

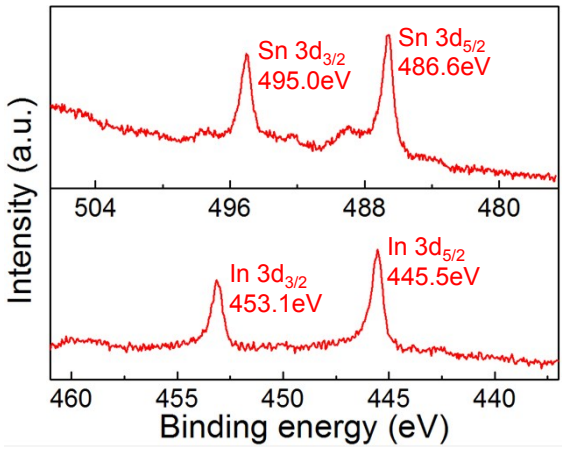

Fig. S4 Sn 3d and In 3d XPS spectra of cotton after 10 times of rubbing treatment.

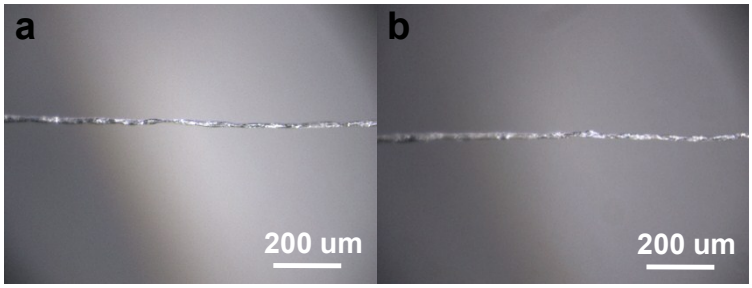

Fig. S5 Optical images of pure cotton fiber before (a) and after 50 times of rubbing treatment (b). Liquid metals are treated with NaOH solution to eliminate the oxides. No liquid metals adhere on the surface of the pure cotton fiber before or after rubbing treatment.

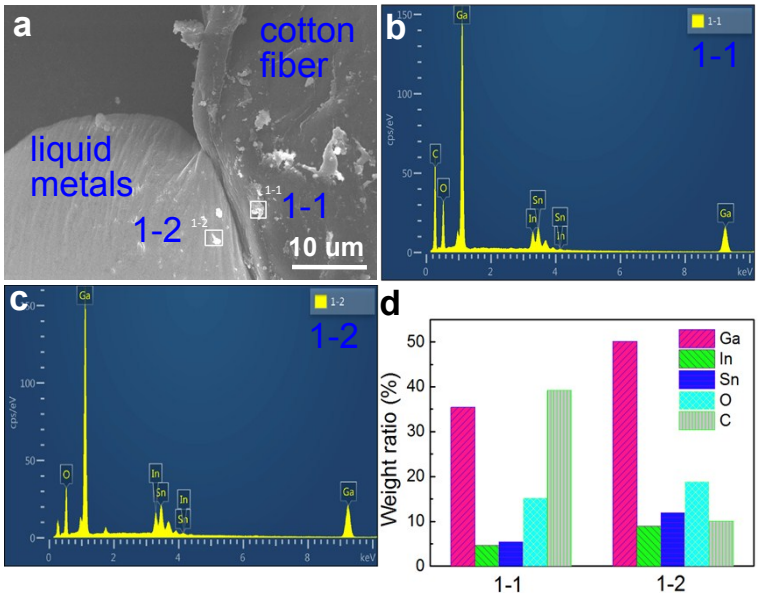

Fig. S6 SEM image (a) of liquid metal droplet adhering to cotton fiber after rubbing treatment, and corresponding EDS analyses (b and c). The EDS analysis results of the layered materials on cotton fiber (labelled as 1-1) and the surface of liquid metal droplet (labelled as 1-2) were showed in b and c, respectively. (d) Weight ratios of Ga, In, Sn, O and C in two samples.

Many layered materials were observed near the interface between metal droplet and fiber. Both the layered materials on cotton fiber (labelled as 1-1) and the surface of liquid metal droplet (labelled as 1-2) showed the characteristic peaks of Ga, In, Sn and O in EDS analysis (Fig. S6b and S6c), which proved that the layered materials were liquid metal oxides. Because the detection depth of EDS can reach micrometer level,

the difference of C and O content detected in the samples may be attributed to the cellulose of the underlying cotton fiber (Fig. S6d).

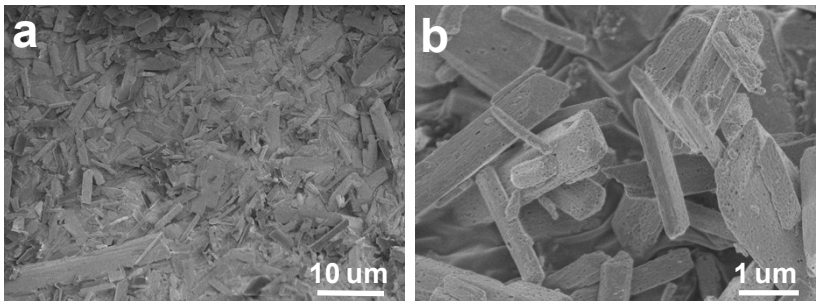

Fig. S7 (a) SEM images of Ga_2O_3 powder and the higher magnification (b).

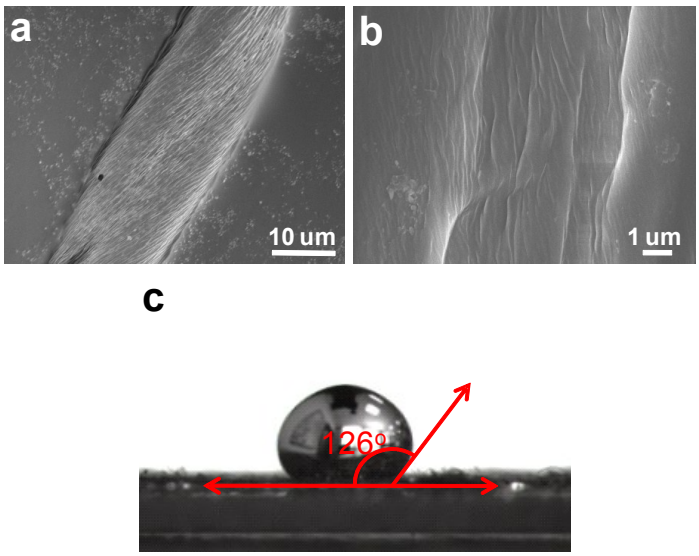

Fig. S8 (a) SEM image of single cotton fiber treated by Ga_2O_3 powder and the higher magnification (b). (c) Static contract angle of liquid metals on cotton treated by Ga_2O_3 powder.

The SEM image shows that there is no obvious Ga_2O_3 powder on the surface of the cotton fiber. Therefore, the static contact angle is only 126°, which is very close to that of pure cotton.

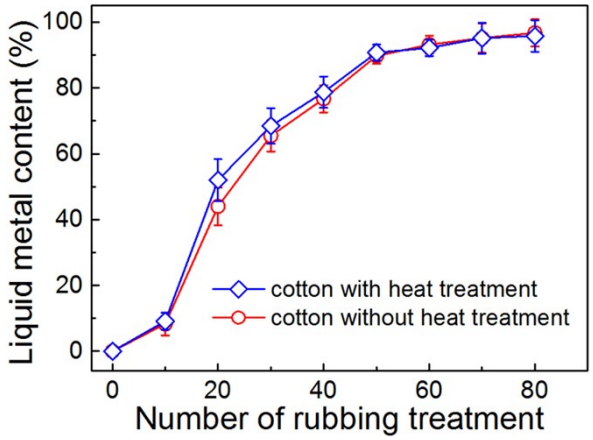

Fig. S9 Effect of the water physisorbed in cotton fibers on the liquid metal content.

The growth rate of liquid metal content in heat treated cotton before 40 times of rubbing treatment was slightly faster than that in the untreated sample. However, the growth curves of the two samples were almost the same after 40 time. The best liquid metal content of the conductor used in the experiment was ~90%, which could be achieved by 50 times of rubbing treatment for samples with or without heat treatment. In other words, the absorbed water had little effect on the liquid metal content of the final product.

Table S1 Specific surface area (SSA) of liquid metals in conductors with different diameters

Diameter of the conductor/mm	Mass of cotton thread/g	Mass of the conductor/g	Liquid metal content/%	Surface area of the conductor /m^2	**SSA of liquid metals in the conductor/m^2/g**
0.28±0.10	0.0225	0.2438	90.8	0.0002638	**0.001192**
0.48±0.27	0.0382	0.3489	89.1	0.0004522	**0.001455**
0.81±0.19	0.0730	0.7101	89.7	0.0007630	**0.001198**
2.20±0.32	0.1025	1.0916	90.6	0.0020724	**0.002095**

The exposed area of liquid metals on the surface layer of the conductor could be quantified by the specific surface area (SSA). The large SSA led to a fast oxidation reaction rate and a high oxidation degree of liquid metals. The SSA of liquid metals in

the conductor could be calculated by the following formula, and the two ends were ignored because of their small area.

$$SSA=\pi dl/(m-m_0) \quad (1)$$

Where d and l were the diameter and length of the conductor, respectively; m_0 represented the mass of the pure cotton thread; and m indicated the mass of the conductor. As shown in Table S1, four conductors with different diameters and similar liquid metal contents (~90 wt%) were studied. The thickest conductor (2.20±0.32 mm) showed the largest SSA of liquid metals, indicative of the faster oxidation reaction rate and the greater oxidation degree.

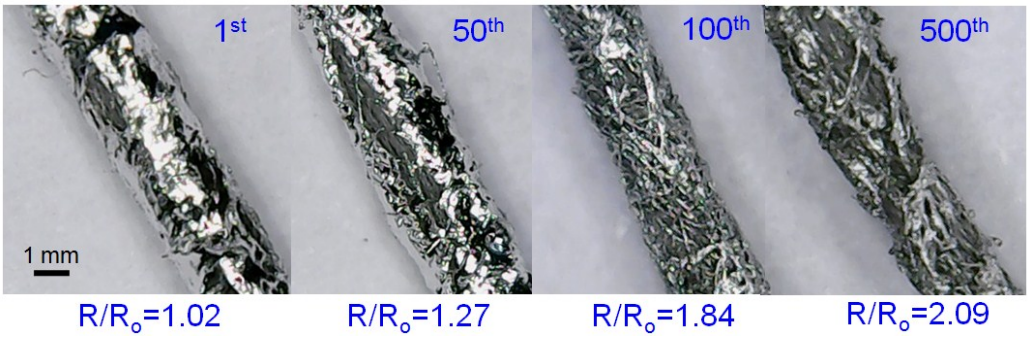

Fig. S10 Optical images of the conductor after different folding test time and their corresponding R/R_o.

After 50 folding tests, some breakage occurs and liquid metals were easily lost through this area. Therefore, there was a great change in resistance. After 100 and 500 times, more liquid metals were lost, resulting in greater resistance of soft conductor.

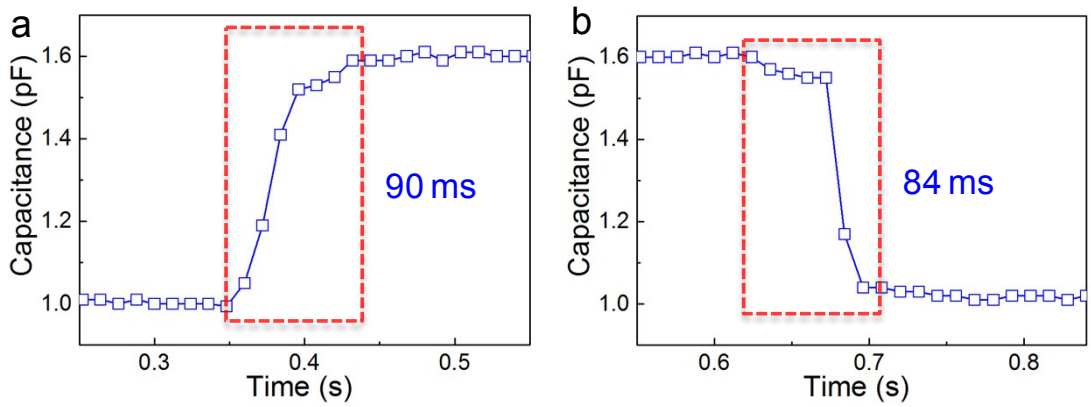

Fig. S11 Response and relaxation time of the soft conductor-based pressure sensor to external loads. (a) A capacitive response time according to external loads was around 90 ms. (b) A relaxation time of the pressure sensor to removal of external load was around 84 ms.

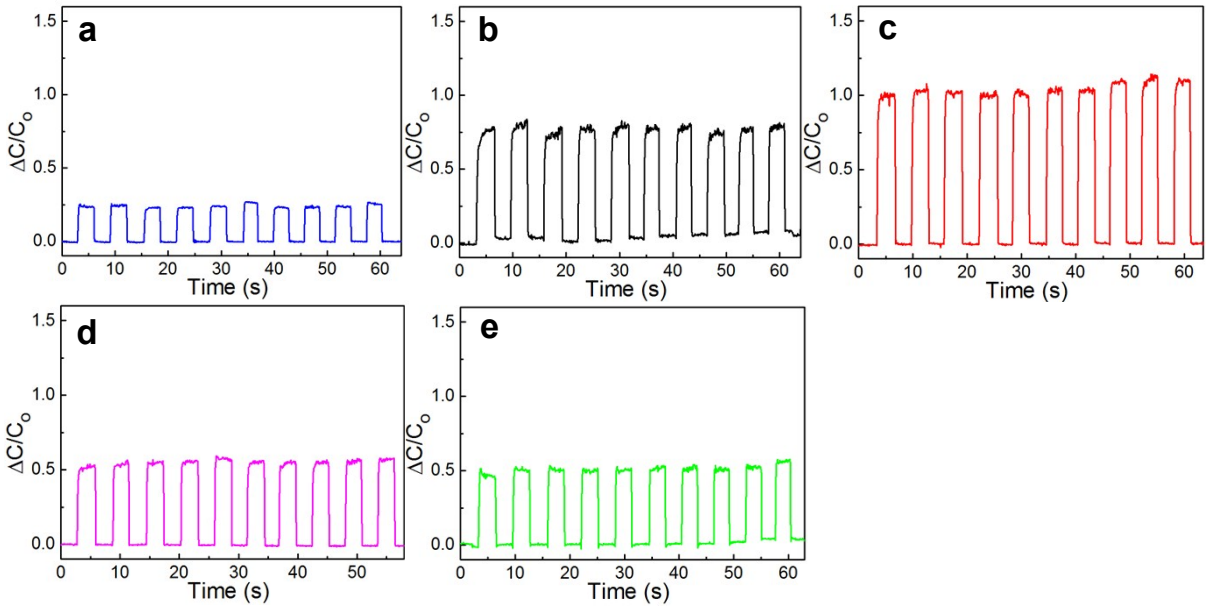

Fig. S12 Capacitive responses to dynamic loading and unloading cycles for a clenched fist: the thumb (a), index (b), middle (c), ring (d) and little finger (e).

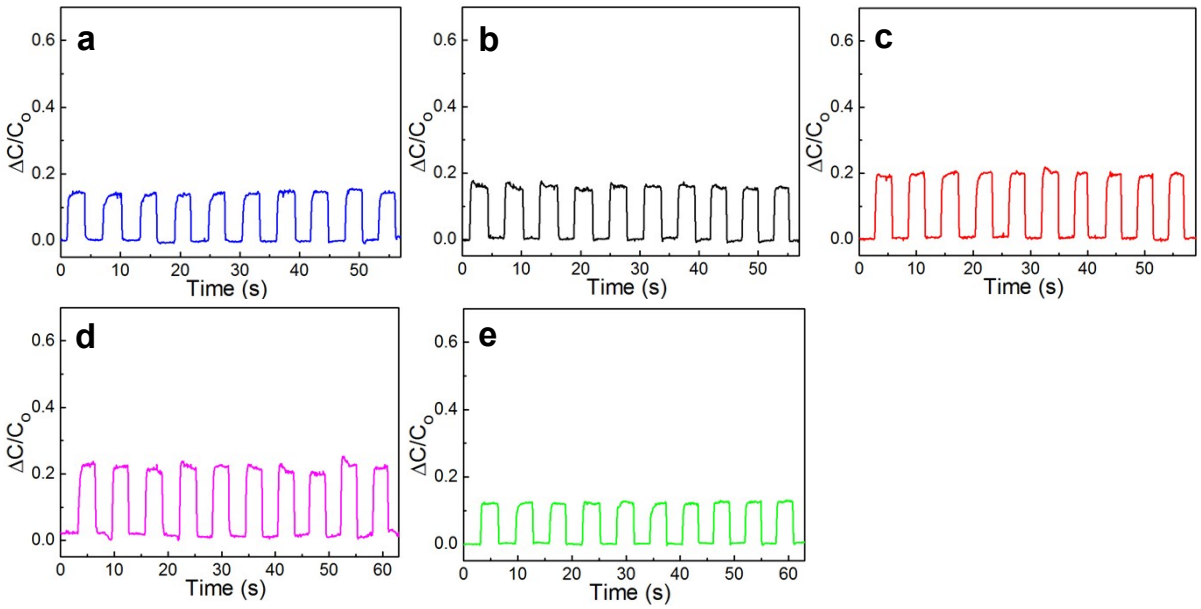

Fig. S13 Capacitive responses to dynamic loading and unloading cycles for holding a tennis ball: the thumb (a), index (b), middle (c), ring (d) and little finger (e).