Coaxial wet-spun yarn supercapacitors for high-energy density and safe wearable electronics

Liang Kou（11129026）, Chao Gao*

Department of Polymer Science and Engineering, Zhejiang University

INTRODUCTION

Yarn supercapacitors (YSCs) hold great potential in future portable and wearable electronics due to their tiny volume, flexibility and weavability. However, low energy density, compared with battery, always limited their development in the area of wearable high-energy density devices. How to enhance their energy density while retaining their intrinsic high specific power is one of the most critical aspects for YSCs. Here we proposed a coaxial wet-spinning assembly approach to continuously spin polyelectrolyte-wrapped graphene/carbon nanotube core-sheath fibres, which were used directly as safe electrodes to assembly two-ply YSCs. The flexible YSCs using liquid and solid electrolytes show ultra-high capacitances of 269 and 177 mF cm^{-2} and energy densities of 5.91 and 3.84 μWh cm^{-2}, respectively. A cloth supercapacitor superior to commercial capacitors was further interwoven from two individual 40 cm-long coaxial fibres. The combination of scalable coaxial wet-spinning technology and excellent performance of YSCs paves the way to wearable and safe electronics.

METHODS & MATERIALS

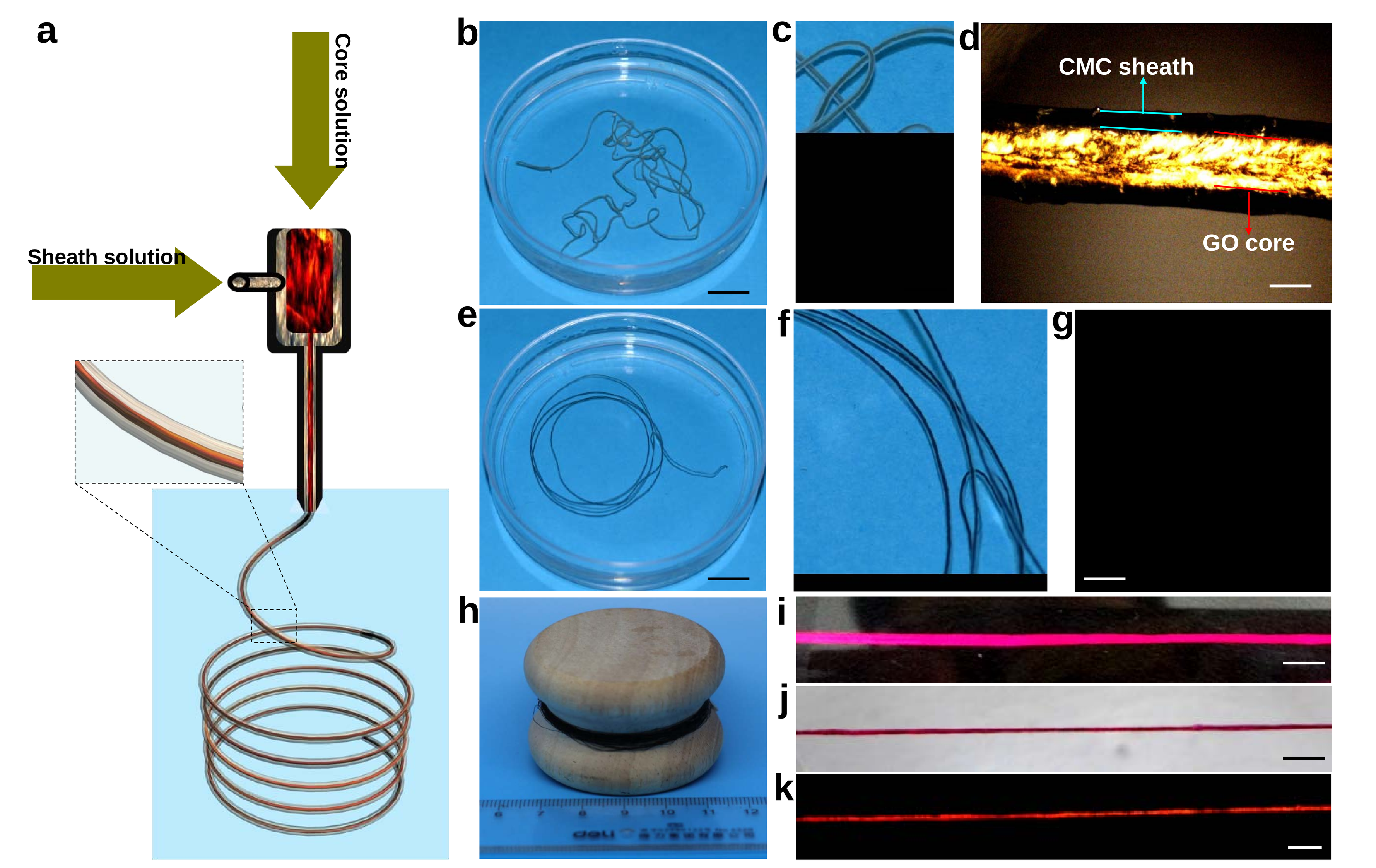

Figure 1｜ Coaxial wet-spinning assembly process and the as-prepared core-sheath fibres. (a) Schematic illustration showing the coaxial spinning process. (b) A single intact wet GO@CMC fibre and its magnified image (c). (d) POM image of wet GO@CMC fibre indicating the core-sheath structure and the well-aligned GO sheets in the core part. (e) A wet RGO@CMC fibre and its magnified images with blue (f) and black (g) background. (h) The macroscopic photo of the RGO@CMC coaxial fibres. Wet (i) and dry (j) coaxial fibres dyed by rhodamine B and its fluorescence photos (k) in the dark under UV irradiation. Scale bars, 1 cm (b, e), 5 mm (c, f, g), 100 μm (d), 2 mm (i, j, k).

RESULTS

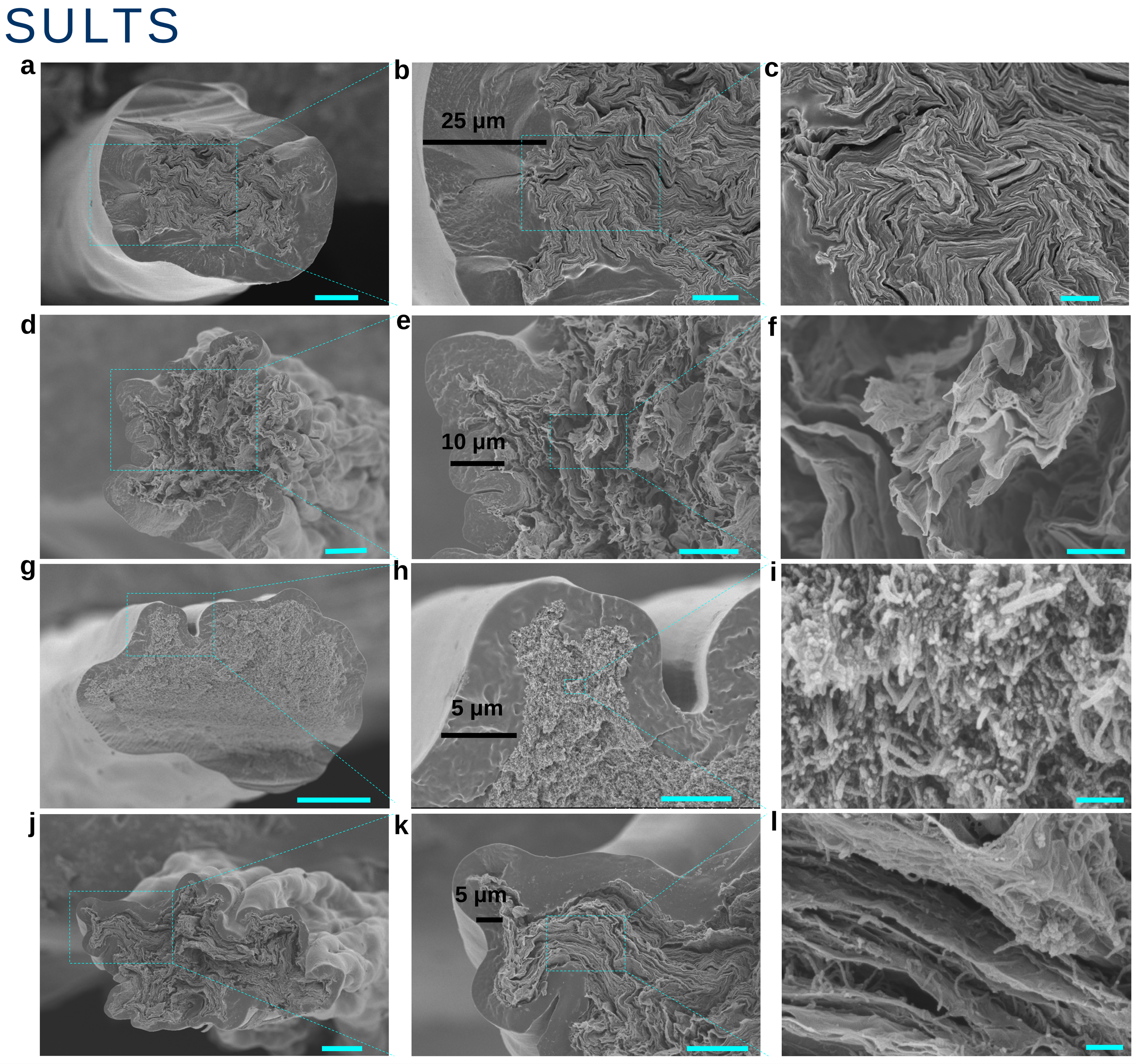

Figure 2 ｜ SEM images of coaxial fibres. (a-c) GO@CMC spun with GO of 20 mg mL^{-1} and CMC of 12 mg mL^{-1}. (d-f) RGO@CMC spun with GO of 20 mg mL^{-1} and CMC of 8 mg mL^{-1}. (g-i) CNT@CMC spun with CNT of 10 mg mL^{-1} and CMC of 8 mg mL^{-1}. (j-l) RGO+CNT@CMC spun with GO and CNT mixture (w/w, 1/1) of 20 mg mL^{-1} and CMC of 8 mg mL^{-1}. Scale bars, 20 μm (a, d, g, j, m), 10 μm (b, h, n), 5 μm (e, k), 2 μm (c, f, i), 0.2 μm (l, o).

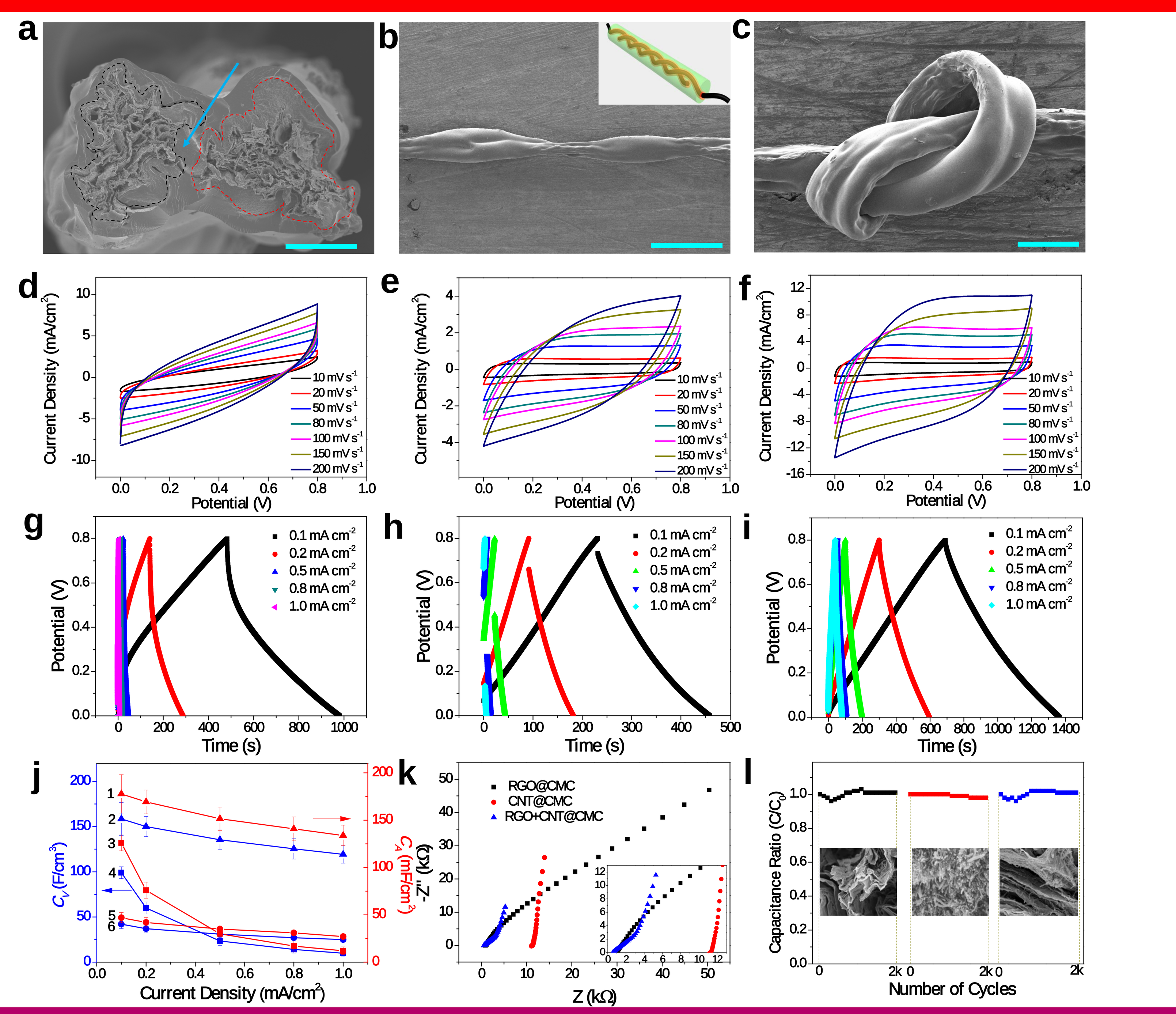

Figure 3｜Two-ply YSCs and their electrochemical properties. SEM images of cross sectional (a) and side (b) view of a two-ply YSC. The arrow area in a is PVA/H_3PO_4 electrolyte and inset of b shows the schematic illustration of YSC. (c) SEM image of a two-ply YSC knot. CV curves of RGO@CMC (d), CNT@CMC (e), and RGO+CNT@CMC (f). GCD curves of RGO@CMC (g), CNT@CMC (h), and RGO+CNT@CMC (i). (j) Dependence of CA and CV on the charge/discharge current density for RGO@CMC (3, 4), CNT@CMC (5, 6) and RGO+CNT@CMC (1, 2) YSCs. We selected five cross sections and used the average value as the cross-sectional areas to determine the error bars. (k) Nyquist plots of RGO@CMC, CNT@CMC, and RGO+CNT@CMC YSCs. (l) Normalized capacitance (*C/C$_0$*, where *C$_0$* is the initial capacitance) versus cycle number for RGO@CMC (left), CNT@CMC (middle), and RGO+CNT@CMC (right) YSCs. Scale bars, 50 μm (a), 500 μm (b), 200 μm (c).

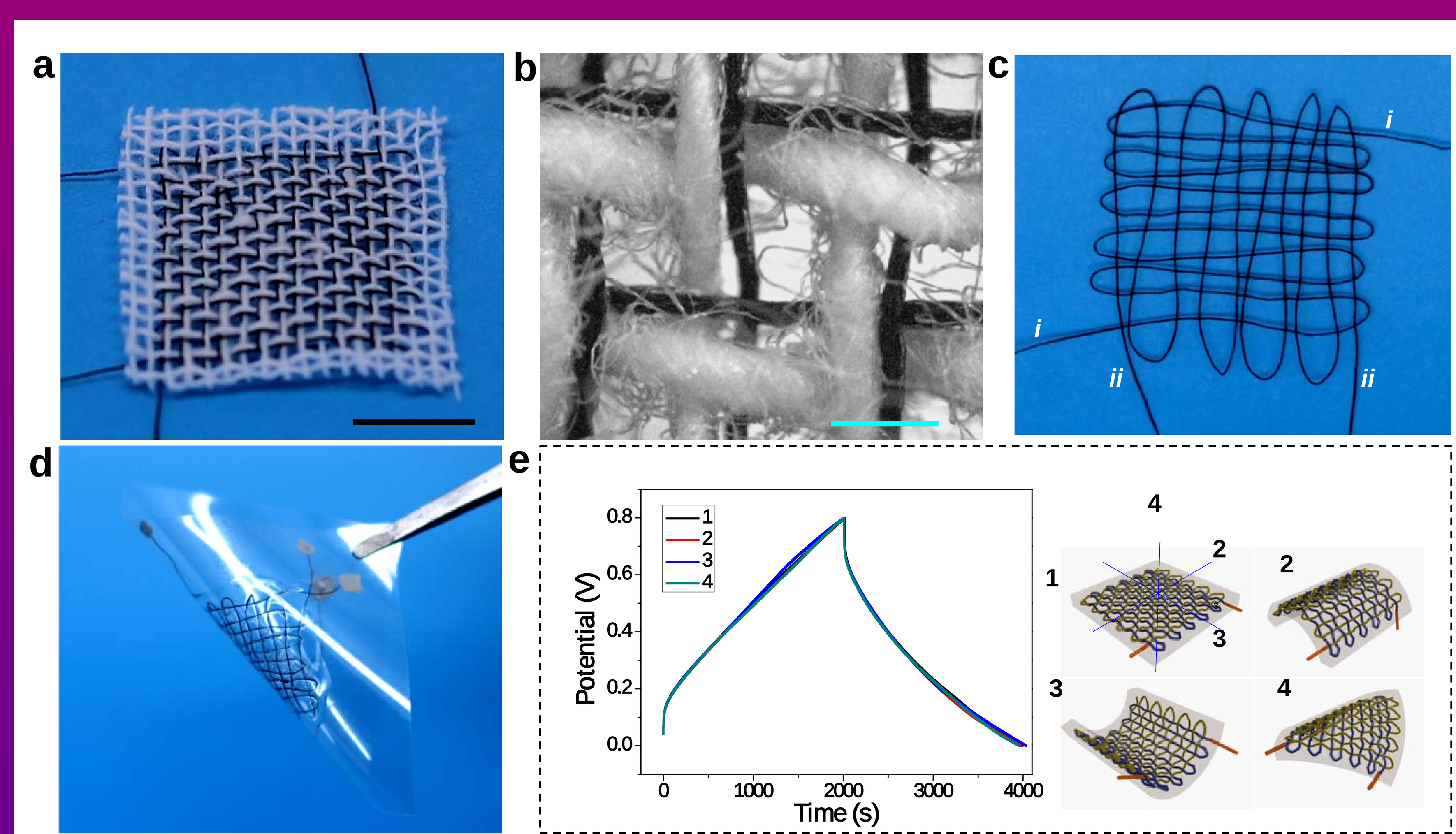

Figure 4｜ Supercapacitor based on the cloth woven by coaxial fibres. (a) Two intact coaxial fibres woven with cotton fibres. (b) Optical macroscopic image of a. (c) Cloth woven by two individual coaxial fibres. (d) Supercapacitor device based on the cloth fabricated by two coaxial fibres (denoted as *i* and *ii*, respectively). (e) GCD curves of the cloth supercapacitor (1 represents initial cloth supercapacitor without bending and 2, 3, 4 show cloth supercapacitor with bending angles of 180º along three directions). Scale bars, 1cm (a) and 200 μm (b).

CONCLUSIONS

In conclusion, we proposed and demonstrated for the first time a coaxial wet-spinning assembly strategy to prepare core-sheath fibres of polymer-wrapped carbon nanomaterials. The as-made coaxial fibres are flexible and robust enough to be intertwined, knotted and woven. Due to the coating of electrically insulative polyelectrolyte, the coaxial fibres were used directly to assembly two-ply intertwined safe YSCs. The resultant RGO+CNT@CMC YSCs showed ultrahigh capacitance, energy density and excellent cycle stability under bending. A highly bendable cloth supercapacitor was woven from two 40 cm-long coaxial fibres, promising the applications of our YSCs in military garment devices, intelligent micro-sensors, and other wearable electronics.

REFERENCES

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