Electronic Supporting Information

Planar integration of flexible micro-supercapacitors with ultrafast charge and discharge based on interdigital nanoporous gold electrodes on a chip

Chao Zhang, Jian Xiao, Lihua Qian, Songliu Yuan, Shuai Wang, and Pengxiang Lei

a School of Physics, Huazhong University of Science and Technology, Wuhan, 430074, P. R. China

b Flexible Electronics Research Center, Huazhong University of Science and Technology, Wuhan, 430074, P. R. China

c School of Chemistry and Chemical Engineering, Huazhong University of Science and Technology, Wuhan, 430074, P. R. China

d School of Chemistry and Chemical Engineering, Hubei University of Technology, Wuhan, 430068, P. R. China

*Corresponding author.

aE-mail: lhqian@hust.edu.cn (L. Q); cE-mail: chmsamuel@hust.edu.cn (S. W); dE-mail: leipxc@mail.china.com (P. L)
**Electrochemical characterization and analysis**

The mass of MnO$_2$ in the electrodes was calculated using the following equation (1):

$$m = \frac{Q}{nF} \times M \quad (1)$$

Where $m$ is the mass of MnO$_2$; $Q$ is total electric quantity for the electrochemical plating by potentiostatic deposition with three electrodes; $n$ is the charge transfer number; $F$ is the faradic constant; and $M$ is the relative molecular mass.

The deposited PPy mass can be evaluated based on the following equation (2):

$$m = \frac{Q}{(2+y)F} \times M \quad (2)$$

Where $m$, $Q$, $y$, $F$ are the mass of the deposited PPy, polymerizing charge, a stoichiometric factor evaluating the PPy insertion degree, and the faradic constant, respectively. $M$ is the molecular weight of the polymer monomer unit ($M = M_{Py-2}$), and $M_{Py}$ is pyrrole molecular weight. A degree of insertion (0.2) was applied.

The areal/volumetric capacitance of the MSC was calculated from galvanostatic charge/discharge curves according to the following equation:

- Areal capacitance:
  $$C_s = \frac{I \times \Delta t}{S \times \Delta V} \quad (3)$$
- Volumetric capacitance:
  $$C_v = \frac{I \times \Delta t}{V \times \Delta V} \quad (4)$$

Where $I$ is the constant discharge current; $\Delta t$ is the time for a full discharge; $S$ ($V$) is the planar area of active materials in the two working electrodes; and $\Delta V$ is the voltage drop on discharge.

The volumetric energy density ($E$) and power densities ($P$) against two electrodes in the device were calculated using the following formulas:

- Volumetric energy density:
  $$E_v = \frac{C_v \times \Delta V^2}{2 \times 3600} \quad (5)$$

- Volumetric power density:
  $$P_v = \frac{E}{\Delta t} \times 3600 \quad (6)$$

Where $\Delta V$ is the operating voltage; $C_v$ is the total capacitance of the device; and $\Delta t$ is the time for a full discharge.
Figure S1. SEM images of NPG/MnO$_2$ composites with the MnO$_2$ plating time of (a) 20 min, (b) 30 min.
**Figure S2.** The plated mass of MnO$_2$ films versus the electroplating time.
Figure S3. EDX spectrum and elemental mapping images of the NPG/MnO$_2$ composite.
Figure S4. SEM images of NPG/PPy composites with the PPy plating time of (a) 20 s, (b) 30 s.
Figure S5. The plated mass of PPy films versus the electroplating time.
**Figure S6.** EDX spectrum and elemental mapping images of the NPG/PPy composite.
Figure S7. TEM images of NPG/MnO$_2$ (a) and NPG/PPy (c); High magnified TEM images of NPG/MnO$_2$ (b) and NPG/PPy (d).
Figure S8. CV curves of NPG/MnO\textsubscript{2} MSC with the MnO\textsubscript{2} plating time of 2 min at scan rates ranging from (a) 5 to 200 mV s\textsuperscript{-1}; (b) 0.5 to 20 V s\textsuperscript{-1}. Galvanostatic charge/discharge curves of NPG/MnO\textsubscript{2} MSC with the MnO\textsubscript{2} plating time of 2 min at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S9. CV curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 5 min at scan rates ranging from (a) 5 to 200 mV s$^{-1}$; (b) 0.5 to 20 V s$^{-1}$. Galvanostatic charge/discharge curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 5 min at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S10. CV curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 10 min at scan rates ranging from (a) 5 to 200 mV s$^{-1}$; (b) 0.5 to 20 V s$^{-1}$. Galvanostatic charge/discharge curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 10 min at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S11. CV curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 20 min at scan rates ranging from (a) 5 to 200 mV s$^{-1}$; (b) 0.5 to 20 V s$^{-1}$. Galvanostatic charge/discharge curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 20 min at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
**Figure S12.** CV curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 30 min at scan rates ranging from (a) 5 to 200 mV s$^{-1}$; (b) 0.5 to 20 V s$^{-1}$. Galvanostatic charge/discharge curves of NPG/MnO$_2$ MSC with the MnO$_2$ plating time of 30 min at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S13. Evolution of the areal capacitance of MSC with various mass loadings of MnO$_2$ as a function of scan rate.
Figure S14. Areal capacitance of NPG/MnO$_2$ MSCs versus the MnO$_2$ plating time.
Figure S15. Evolution of the areal capacitance of MSC with various mass loadings of PPy as a function of scan rate.
**Figure S16.** CV curves of NPG/PPy MSC with the PPy plating time of 2 s at scan rates ranging from (a) 5 to 200 mV s\(^{-1}\); (b) 0.5 to 20 V s\(^{-1}\). Galvanostatic charge/discharge curves of NPG/PPy MSC with the PPy plating time of 2 s at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S17. CV curves of NPG/PPy MSC with the PPy plating time of 5 s at scan rates ranging from (a) 5 to 200 mV s\(^{-1}\); (b) 0.5 to 20 V s\(^{-1}\). Galvanostatic charge/discharge curves of NPG/PPy MSC with the PPy plating time of 5 s at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S18. CV curves of NPG/PPy MSC with the PPy plating time of 10 s at scan rates ranging from (a) 5 to 200 mV s\(^{-1}\); (b) 0.5 to 20 V s\(^{-1}\). Galvanostatic charge/discharge curves of NPG/PPy MSC with the PPy plating time of 10 s at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S19. CV curves of NPG/PPy MSC with the PPy plating time of 20 s at scan rates ranging from (a) 5 to 200 mV s\(^{-1}\); (b) 0.5 to 20 V s\(^{-1}\). Galvanostatic charge/discharge curves of NPG/PPy MSC with the PPy plating time of 20 s at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S20. CV curves of NPG/PPy MSC with the PPy plating time of 30 s at scan rates ranging from (a) 5 to 200 mV s\(^{-1}\); (b) 0.5 to 20 V s\(^{-1}\). Galvanostatic charge/discharge curves of NPG/PPy MSC with the PPy plating time of 30 s at different current from (c) 0.002 to 0.01 mA; (d) 0.02 to 0.1 mA.
Figure S21. IR drop of NPG based MSC with the MnO$_2$ plating time of 10 min or the PPy plating time of 10 s at various current densities.
Figure S22. Capacitance retention of the flexible device after 1000 bending cycles with a bending angle of 90°. The inset is the galvanostatic charge/discharge curves of NPG/MnO$_2$ MSC after bending.
Figure S23. Areal capacitance of AMSC based 10 min MnO$_2$ plating and 10 s PPy plating as a function of scan rate.