Supporting Information

Study on Importance of Uniformity and Nanoparticle Size of ZIF-8 Carbon Nanoarchitecture for Enhancing Electrochemical Property

Donggyun Kim[a], Jinhyeon Park[a], Seonghyeon Jung,[a] Jieun Jang[a], Minsu Han[b], Minjun Kim[b], Wenkai Zhu[c], Woo-Jin Song[d], Yusuke Yamauchi[b], Jeonghun Kim[a]*

[a] Department of Chemical and Biomolecular Engineering, Yonsei University, Seoul 03722, Republic of Korea

[b] Australian Institute for Bioengineering and Nanotechnology (AIBN), The University of Queensland, Brisbane, Queensland 4072, Australia

[c] College of Chemistry and Materials Engineering, Zhejiang A&F University, Hangzhou 311300, China

[d] Department of Organic Materials Engineering, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon, 34134 Republic of Korea

* Corresponding author.

E-mail address: jhkim03@yonsei.ac.kr (Jeonghun Kim)

Table S1. Summary of the synthesis conditions for all samples.

Samples	$Zn(OAc)_2$ (g)	2-mIm (g)	Water content (mL)	Pouring time (s)	Pour order	Stirring
ZIF-8-m1	1.5	6.73	25	30	Zn to 2-mIm	750 rpm
ZIF-8-m2		6.73	25	3	Zn to 2-mIm	750 rpm
ZIF-8-m3		6.73	25	1	Zn to 2-mIm	750 rpm
ZIF-8-m4		6.73	35	1	Zn to 2-mIm	750 rpm
ZIF-8-m5		5.21	25	1	Zn to 2-mIm	750 rpm
ZIF-8-n		6.73	25	1	2-mIm to Zn	200 rpm

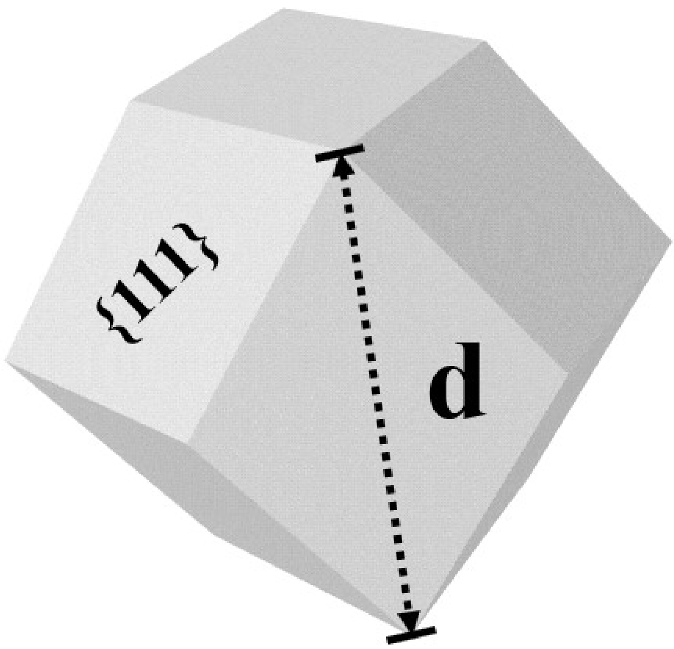

Figure S1. Schematic illustration of the measurement of the size (d) of the ZIF-8 particle with a rhombic dodecahedron shape.

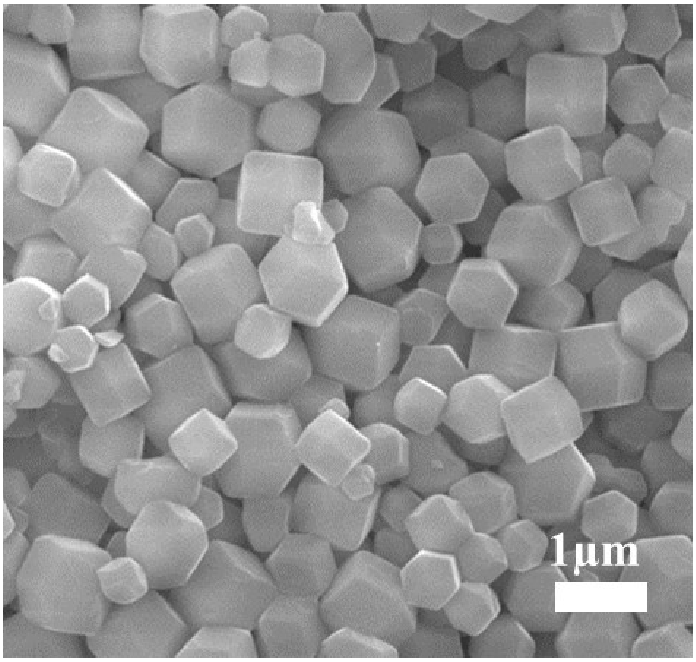

Figure S2. Scanning electron microscopy (SEM) images of ZIF-8-n.

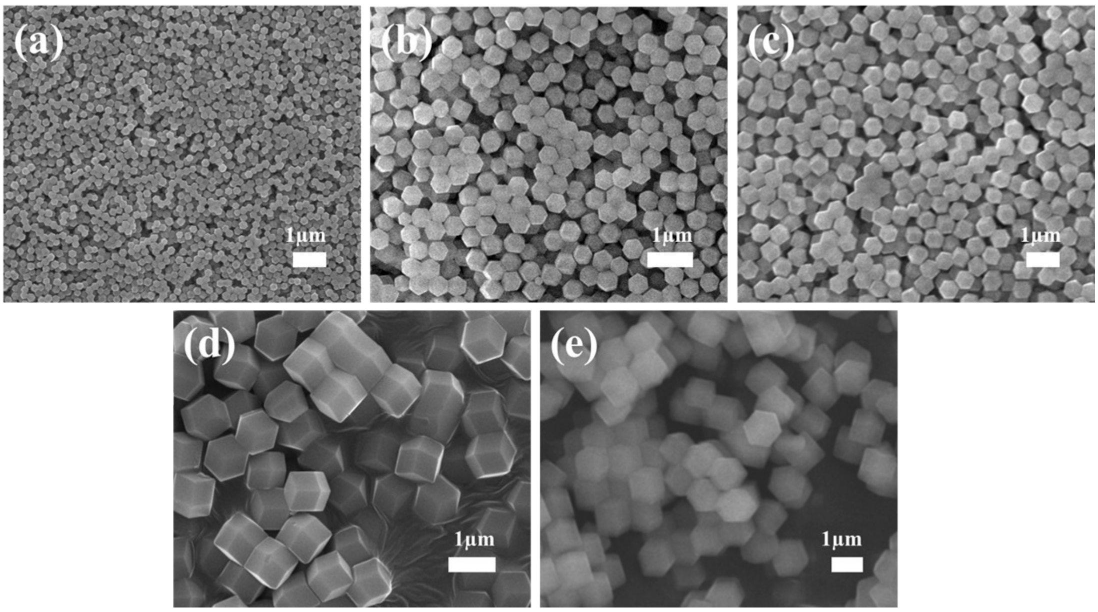

Figure S3. SEM images of (a) ZIF-8-m1, (b) ZIF-8-m2, (c) ZIF-8-m3, (d) ZIF-8-m4, and (e) ZIF-8-m5.

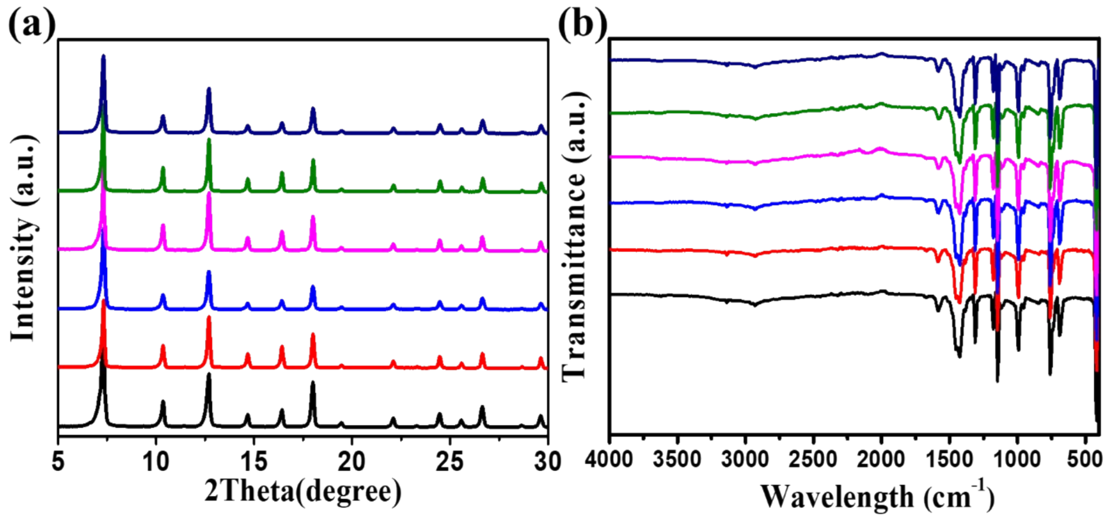

Figure S4. (a) X-ray diffraction (XRD) patterns and (b) Fourier transform infrared (FT-IR) spectra (Black: ZIF-8-m1, Red: ZIF-8-m2, Blue: ZIF-8-m3, Pink: ZIF-8-m4, Green: ZIF-8-m5, Navy: ZIF-8-n).

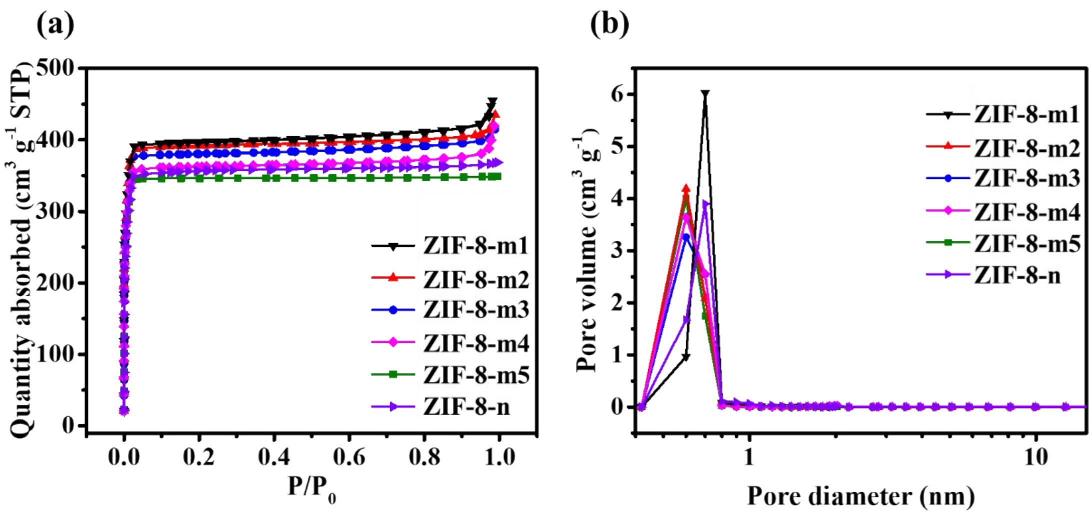

Figure S5. (a) N_2 adsorption–desorption isotherms, and (b) pore size distribution of the ZIF-8 samples.

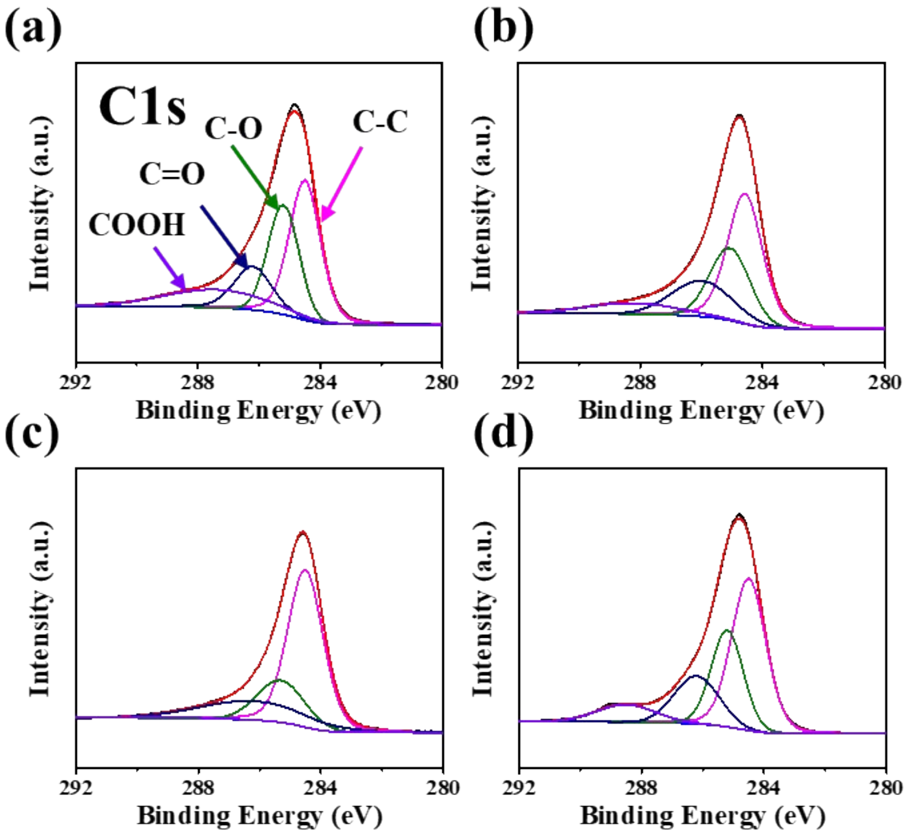

Figure S6. X-ray photoelectron spectroscopy (XPS) profiles of the C1s of (a) ZIF-8-C-m2, (b) ZIF-8-C-m3, (c) ZIF-8-C-m4, and (d) ZIF-8-C-m5.

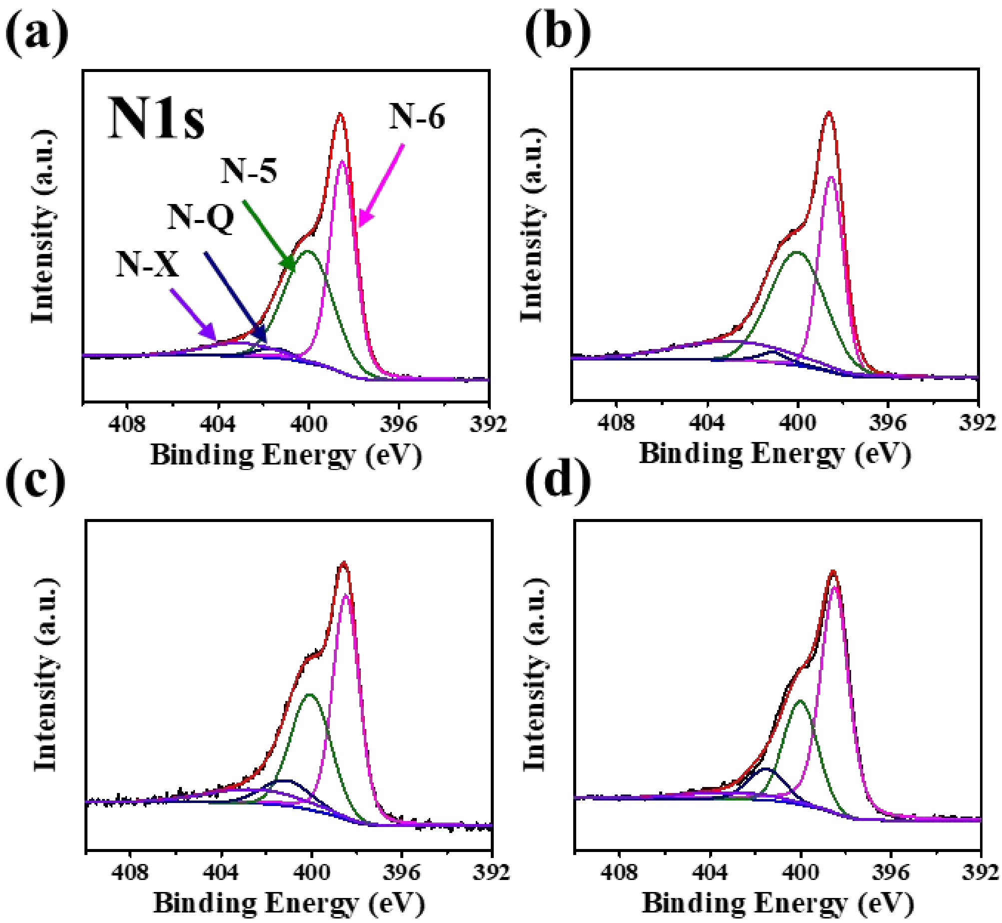

Figure S7. N1s XPS profiles of: (a) ZIF-8-C-m2, (b) ZIF-8-C-m3, (c) ZIF-8-C-m4, and (d) ZIF-8-C-m5.

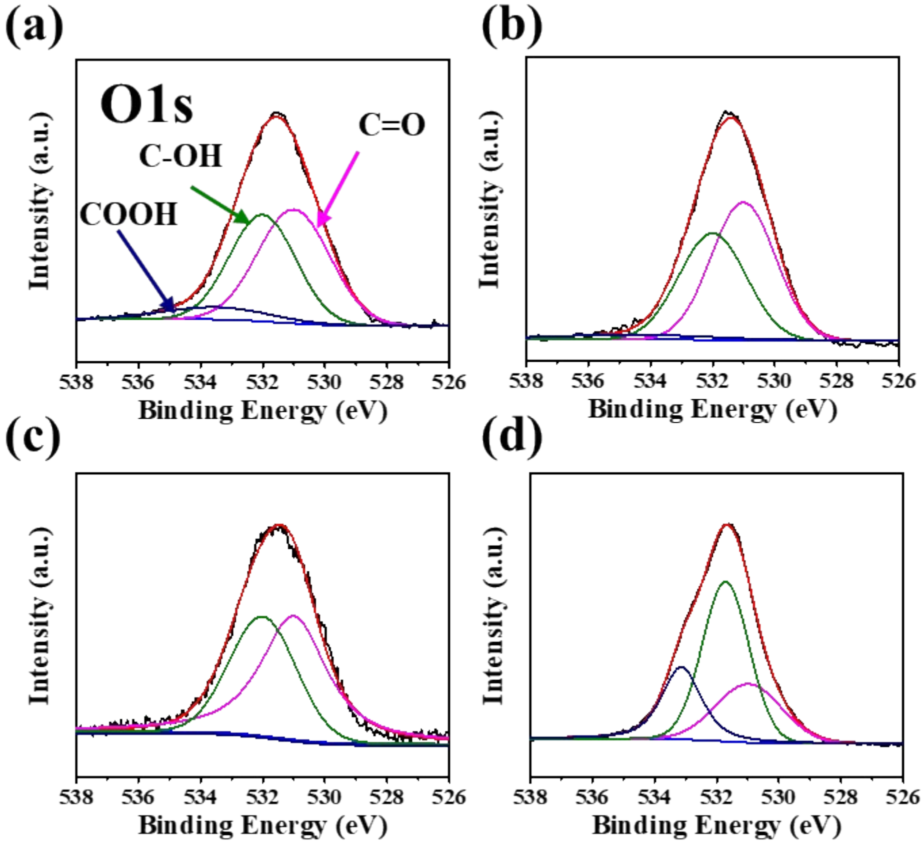

Figure S8. O1s XPS profiles of: (a) ZIF-8-C-m2, (b) ZIF-8-C-m3, (c) ZIF-8-C-m4, and (d) ZIF-8-C-m5.

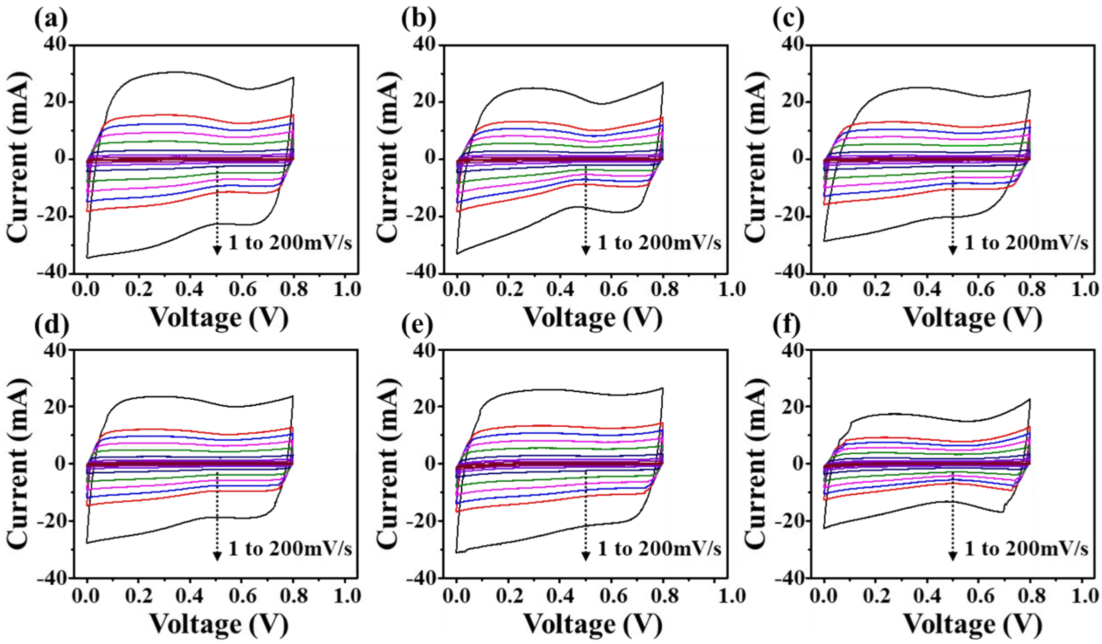

Figure S9. Cyclic voltammetry (CV) curves of (a): ZIF-8-C-m1 (b): ZIF-8-C-m2, (c): ZIF-8-C-m3, (d): ZIF-8-C-m4, (e): ZIF-8-C-m5, (f): ZIF-8-C-n at 1, 2, 5, 10, 20, 40, 60, 80, 100, and 200 mV s^{-1}.

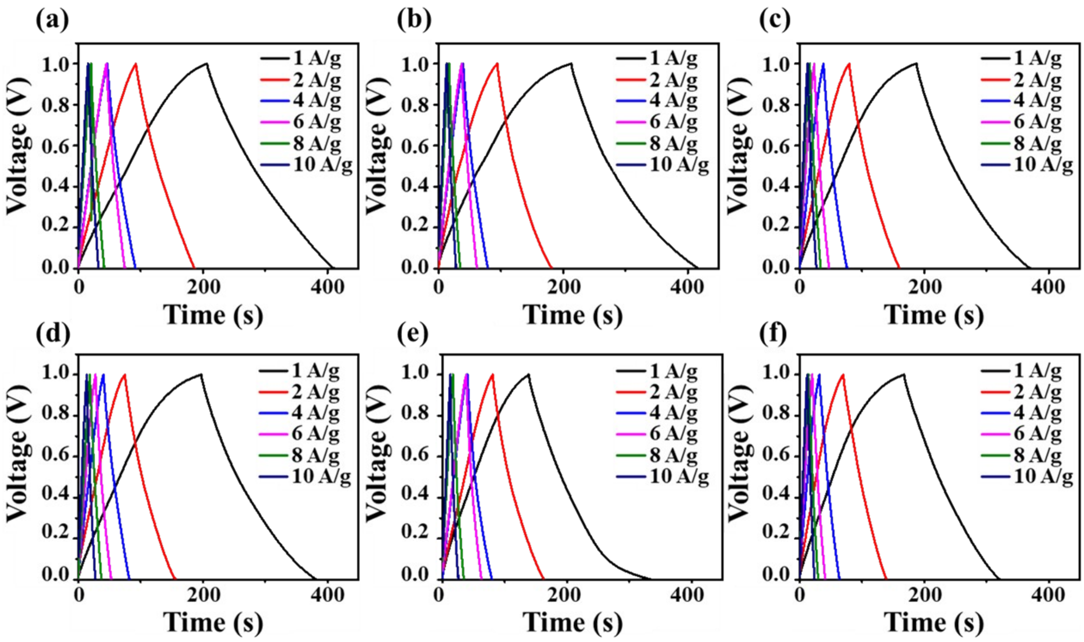

Figure S10. CV and galvanostatic charge–discharge (GCD) curves of: (a) ZIF-8-C-m1, (b) ZIF-8-C-m2, (c) ZIF-8-C-m3, (d) ZIF-8-C-m4, (e) ZIF-8-C-m5, and (f) ZIF-8-C-n at 1, 2, 4, 6, 8, 10 A g^{-1}.

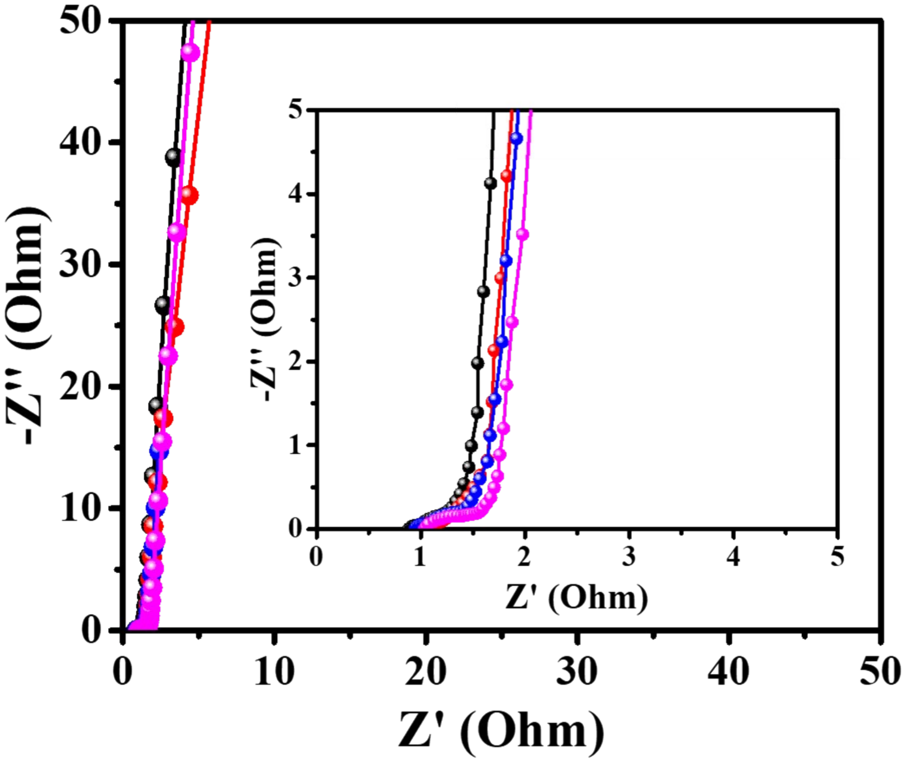

Figure S11. Nyquist plots of ZIF-8-C-m2 (black), ZIF-8-C-m3 (red), ZIF-8-C-m4 (blue), and ZIF-8-C-m5 (pink).

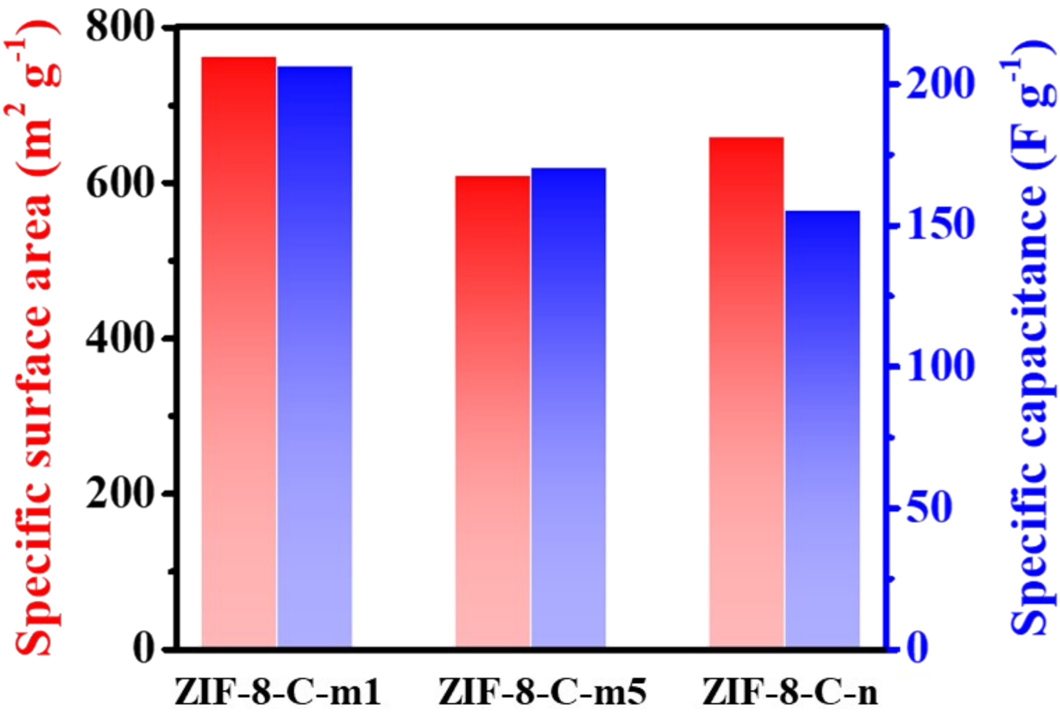

Figure S12. Comparison of the relative specific surface area and specific capacitance of ZIF-8-C-m1, ZIF-8-C-m5, and other ZIF-8-C-n samples.

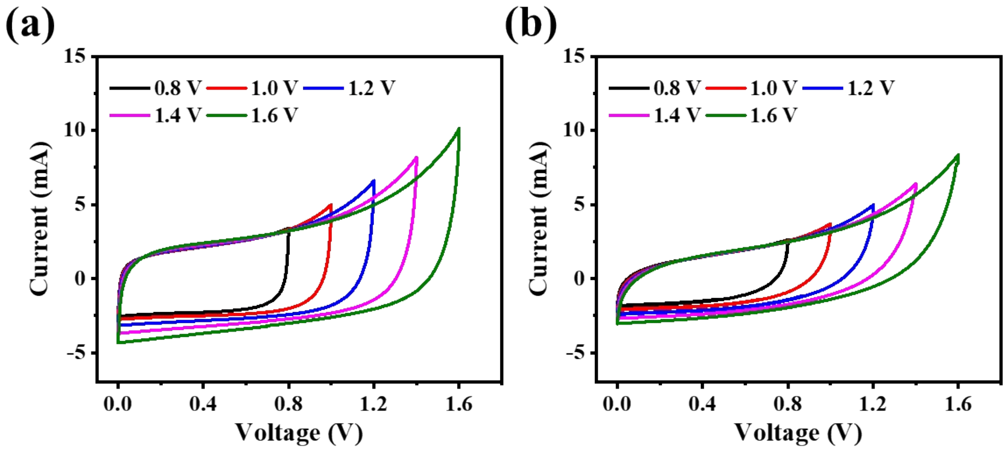

Figure S13. CV curves at 50 mV·s^{-1} under different voltage windows of ZIF-8-C-m5, and ZIF-8-C-n in the two-electrode system.

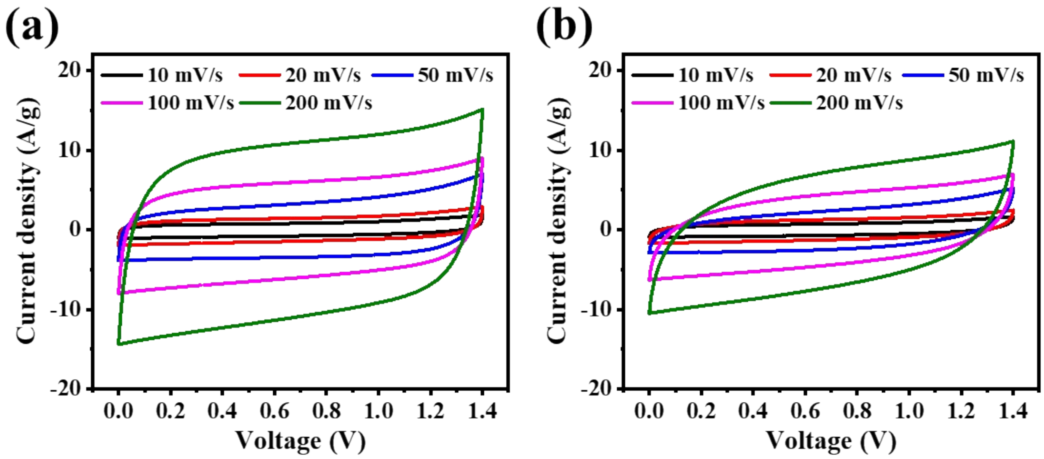

Figure S14. CV curves at different scan rates from 10 to 200 mV·s^{-1} of ZIF-8-C-m5, and ZIF-8-C-n in the two-electrode system.

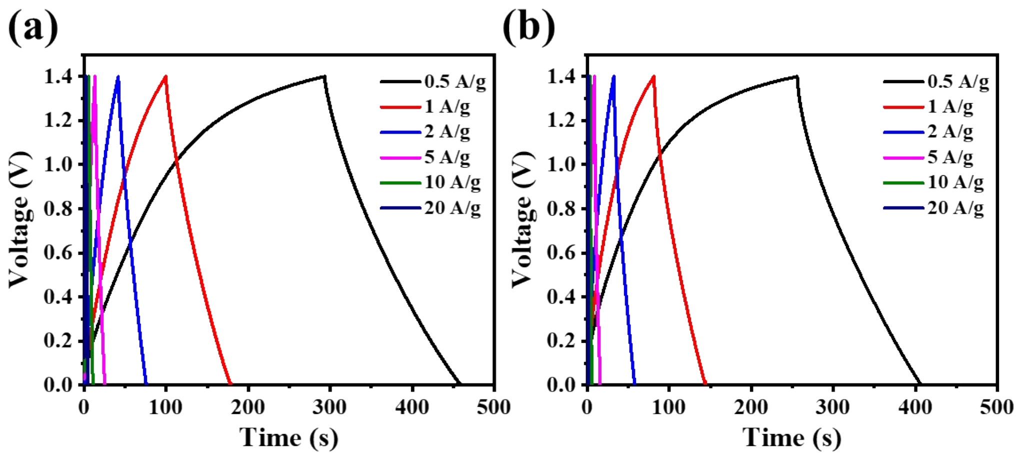

Figure S15. GCD curves at various current densities (0.5–20 $A \cdot g^{-1}$) of ZIF-8-C-m5, and ZIF-8-C-n in the two-electrode system.

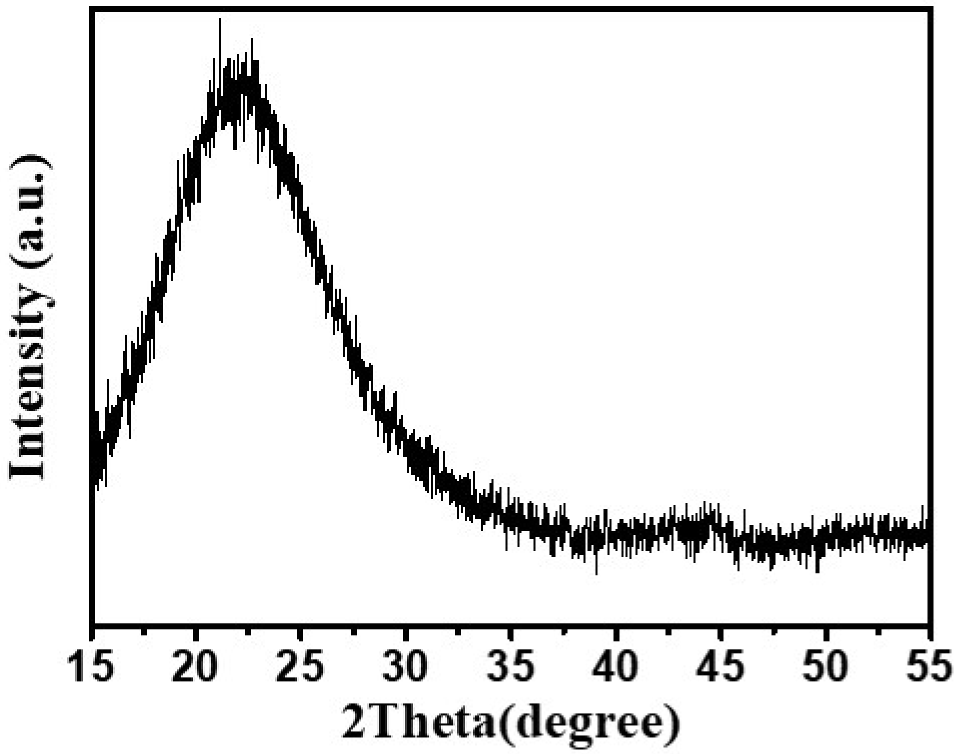

Figure S16. Ex-situ XRD patterns of ZIF-8-C-m1 after 10,000 cycle stability test in the flexible symmetric device system.

Table S2. Results of the BET analysis of the ZIF-8-derived carbon with different particle sizes.

Sample	S_{bet} (m^2/g)	V_{total} (cm^3/g)	V_{micro} (cm^3/g)	D_{avg} (nm)
ZIF-8-m1	1206.5	0.7039	0.5998	1.27
ZIF-8-m2	1119.2	0.6325	0.5627	1.14
ZIF-8-m3	1110.1	0.6249	0.5729	1.10
ZIF-8-m4	1092	0.6021	0.5539	1.24
ZIF-8-m5	1040.2	0.5926	0.5793	1.11
ZIF-8-n	1073.2	0.5821	0.5402	1.14

Table S3. XPS data of the ZIF-8 and ZIF-8-C samples.

Sample	C (at%)	N (at%)	O (at%)	Zn (at%)
ZIF-8-m1	62.11	27.89	1.29	8.71
ZIF-8-C-m1	76.93	16.11	6.96	-
ZIF-8-C-m2	78.6	15.77	5.63	-
ZIF-8-C-m3	81.15	12.77	6.08	-
ZIF-8-C-m4	81.13	12.91	5.96	-
ZIF-8-C-m5	81.5	11.31	7.19	-
ZIF-8-C-n	79.22	11.31	9.47	-

Table S4. Specific capacitance (F g^{-1}) of the ZIF-8-C samples calculated from the CV curves obtained at different scan rates.

Scan rate (mV s^{-1})	ZIF-8-C-m1	ZIF-8-C-m2	ZIF-8-C-m3	ZIF-8-C-m4	ZIF-8-C-m5	ZIF-8-C-n
1	178.47	156.56	164.14	150.48	140.53	112.02
5	165.28	143.39	142.47	138.31	130.21	109.12
10	162.36	140.43	137.57	136.68	129.60	107.43
20	158.21	134.47	133.25	132.72	126.12	103.33
40	153.13	127.68	128.47	127.72	122.07	98.14
60	149.43	122.94	125.31	124.13	119.26	94.73
80	146.31	119.24	122.77	121.37	116.96	91.96
100	143.64	116.15	120.52	118.79	114.99	89.65
200	132.54	103.97	111.12	100.91	107.19	80.37

Table S5. Specific capacitance (F g^{-1}) of the ZIF-8-C samples calculated from the GCD curves at different current densities.

Current densities ($A\ g^{-1}$)	**ZIF-8-C-m1**	**ZIF-8-C-m2**	**ZIF-8-C-m3**	**ZIF-8-C-m4**	**ZIF-8-C-m5**	**ZIF-8-C-n**
1	206.4	201.54	196.54	193	183.27	155.34
2	188.02	189.01	172.73	173.36	150.52	142.2
4	180.18	170.89	163.64	166.72	139.71	131.32
6	175.38	158.91	160.53	151.1	132.54	124.26
8	168.8	152.19	146.49	146.2	130.87	120
10	165.6	149	142.3	138.8	125.42	117.8

Table S6. Series resistance (R_s) and charge transfer resistance (R_{ct}) of ZIF-8-C samples estimated from the Nyquist plot.

	ZIF-8-C-m1	**ZIF-8-C-m2**	**ZIF-8-C-m3**	**ZIF-8-C-m4**	**ZIF-8-C-m5**	**ZIF-8-C-n**
R_s (Ω)	0.9145	0.93405	0.97758	0.95804	1.0376	1.0253
R_{ct} (Ω)	0.2124	0.2323	0.2334	0.4187	0.493	0.5718

Table S7. Comparison of the specific capacitance of various previously reported ZIF-8-derived carbon materials for supercapacitors.

Samples	**Specific capacitance ($F\cdot g^{-1}$)**	**Current density ($A\cdot g^{-1}$)**	**Cycle number**	**Capacitance retention (%)**	**Particle size (nm)**	**Power density ($W\cdot kg^{-1}$)**	**Energy density ($Wh\cdot kg^{-1}$)**	**Ref**
MPC	148.4	2	-	-	85	-	-	1
CNT@CZIF-1	168	0.5	1,000	86.40	20	-	-	2
C-ZIF-8	155.9	1	10,000	95.5	50	-	-	3
NCGs	225	0.5	10,000	96.60	50	447	12.7	4
C(ZIF-8)	130	1	-	-	100	-	-	5
PC-900	173	1	-	-	150	650	7.5	6
NPC	184.4	1	-	-	200	-	-	7
N-HPC-900	182.5	0.2	5,000	94.79	200	50	4.46	8
ZPC-900	185.9	1	-	-	800	-	-	9
HPC NPs	134.5	1	10,000	90.70	480	-	-	10
Assy-ZIF-8-DC	170	1	60,000	96.00	110	105	5.9	11
ZIF-8/GO	95	1	-	-	500	-	-	12
This work	206.4	1	10,000	99.65	147	350	19.4	-

References

1. M. Kim, X. Xu, R. Xin, J. Earnshaw, A. Ashok, J. Kim, T. Park, A. K. Nanjundan, W. A. El-Said and J. W. Yi, *ACS applied materials & interfaces*, 2021, **13**, 52034-52043.
2. L. Wan, E. Shamsaei, C. D. Easton, D. Yu, Y. Liang, X. Chen, Z. Abbasi, A. Akbari, X. Zhang and H. Wang, *Carbon*, 2017, **121**, 330-336.
3. Y. Wang, B. Chen, Y. Zhang, L. Fu, Y. Zhu, L. Zhang and Y. Wu, *Electrochimica Acta*, 2016, **213**, 260-269.
4. L. Wang, C. Wang, H. Wang, X. Jiao, Y. Ouyang, X. Xia, W. Lei and Q. Hao, *Electrochimica Acta*, 2018, **289**, 494-502.
5. H. Yu, W. Zhu, H. Zhou, J. Liu, Z. Yang, X. Hu and A. Yuan, *RSC advances*, 2019, **9**, 9577-9583.
6. H. Zhang, L. Fang, Y. Guo, Z. Wang, H. Hu, W. He and P. Wang, *Journal of Energy Storage*, 2024, **80**, 110138.
7. Z. Shang, X. An, S. Nie, N. Li, H. Cao, Z. Cheng, H. Liu, Y. Ni and L. Liu, *Journal of Bioresources and Bioproducts*, 2023, **8**, 292-305.
8. Z. Shang, X. An, L. Liu, J. Yang, W. Zhang, H. Dai, H. Cao, Q. Xu, H. Liu and Y. Ni, *Carbohydrate Polymers*, 2021, **251**, 117107.
9. C. Guo, G. Li, Y. Wu, X. Wang, Y. Niu and J. Wu, *Energies*, 2023, **16**, 7232.
10. Y. Long, X. An, H. Zhang, J. Yang, L. Liu, Z. Tian, G. Yang, Z. Cheng, H. Cao and H. Liu, *Chemical Engineering Journal*, 2023, **451**, 138877.
11. Y. Bu, W. Jiang, H. Zhang, Q. Kang, Y. Zhou, T. Sun, J. Lian, Q. Xu, M. Zhang and H. Zhuang, *Journal of Power Sources*, 2023, **563**, 232786.
12. W. Zhang, Y. Tan, Y. Gao, J. Wu, J. Hu, A. Stein and B. Tang, *Journal of Applied Electrochemistry*, 2016, **46**, 441-450.