

Supporting information

Hierarchical holey reduced graphene oxide-carbon quantum dot hybrid conductive additive enabling high-rate and long-cycle LiFePO₄ cathodes

Ben Liang^a, Junhong Lu^a, Yanlin Zhang^a, Haoyang Jiang^a, Meiling Ji^a, Chunfeng Shi^{b,*}, Dafang He^{a,*}, and Guangyu He^{a,*}

^a Key Laboratory of Advanced Catalytic Materials and Technology, Advanced Catalysis and Green Manufacturing Collaborative Innovation Center, Changzhou University, Changzhou 213164, Jiangsu Province, China.

^b State Key Laboratory of Petroleum Molecular & Process Engineering, Sinopec Research Institute of Petroleum Processing, College Road 18, Haidian District, Beijing 100083, China.

***Corresponding Author:**

E-mail: dafanghe@cczu.edu.cn; hegy@cczu.edu.cn

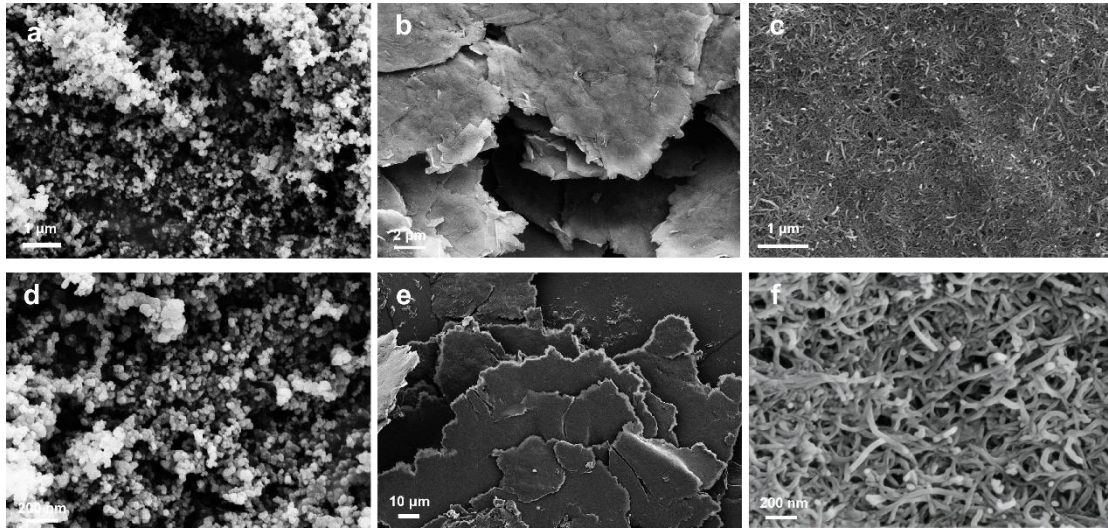


Fig. S1. (a-d) SEM images of SP; (b-e) GN; (c-f) CNT.

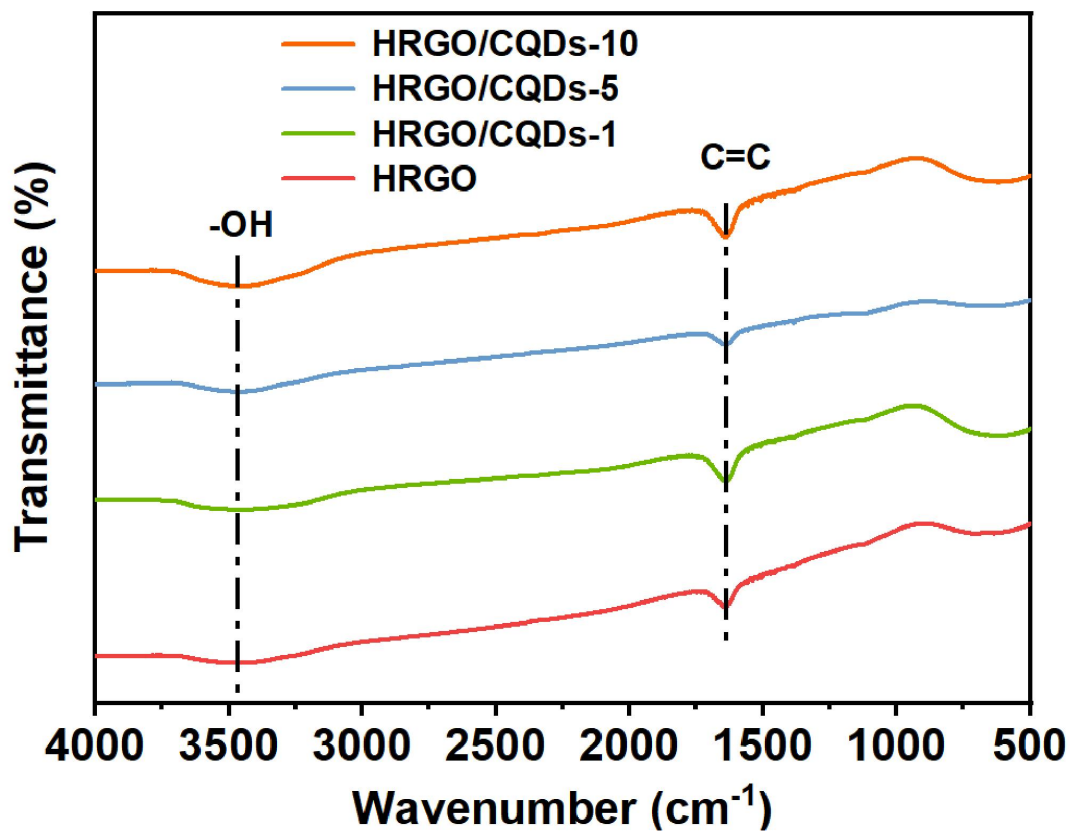


Fig. S2. FT-IR spectra of the pure HRGO/CQDs-1, HRGO/CQDs-5 and HRGO/CQDs-10.

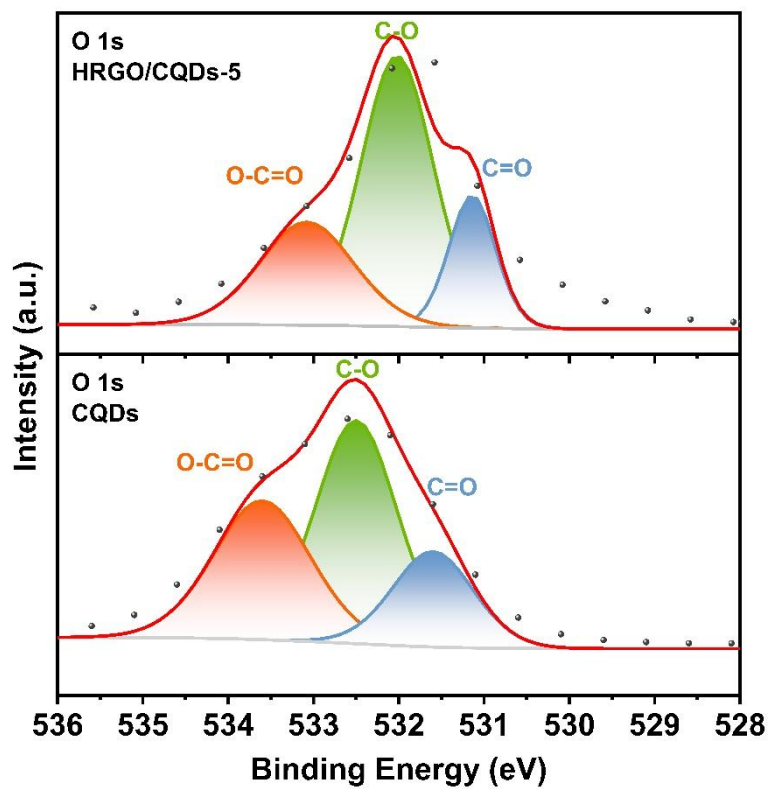


Fig. S3. High resolution XPS O 1s spectrum of the HRGO/CQDs-5 and CQDs.

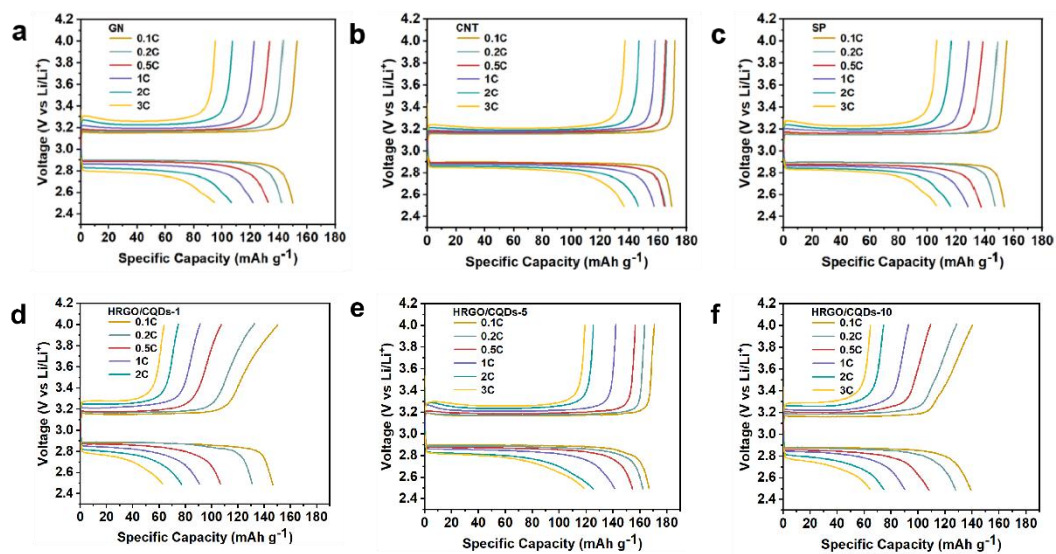


Fig. S4. (a) Typical galvanostatic charge-discharge curves of the GN and (b) CNT and (c) SP and (d) HRGO/CQDs-1 and (e) HRGO/CQDs-5 and (f) HRGO/CQDs-10 cathode at different rates.

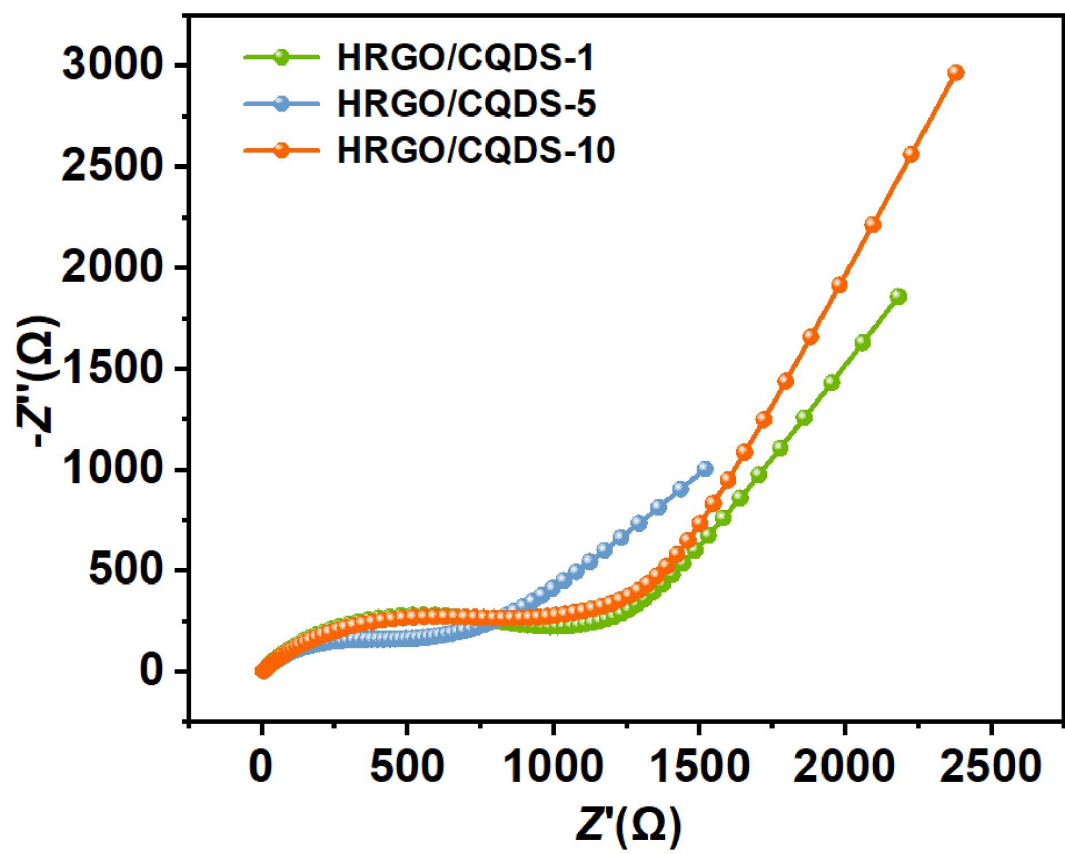


Fig. S5. Electrochemical impedance spectroscopy (EIS) of LiFePO₄ batteries based on the HRGO/CQDs-1, HRGO/CQDs-5 and HRGO/CQDs-10 conductive agent.

Table. S1. Resistivity and conductivity of different conductive agents

Samples	Resistivity ($\Omega \cdot \text{cm}$)	conductivity (S cm^{-1})
HRGO/CQDs-1	0.045	22.015
HRGO/CQDs-5	0.023	43.203
HRGO/CQDs-10	0.032	30.506

Table. S2. Performance comparison of the prepared conductive agent with reference materials in LiFePO₄ applications

Cathode material	Conductive agent	Additive	1C Rate (mAh g ⁻¹)	Refs
LiFePO ₄ @C	10%CNT-5	10%PVDF	129	[1]
LiFePO ₄	10%rGO	10%PVDF	120	[2]
LiFePO ₄ @C	10%CB-5	10%PVDF	120	[3]
LiFePO ₄	10%KB	5%BC	137	[4]
LiFePO ₄	2%HRGO/CQDs-5	3%PVDF	134	This work

References:

1. M. Chen, F.M. Liu, S.S. Chen, Y.J. Zhao, Y. Sun, C.S. Li, Z.Y. Yuan, X. Qian and R. Wan, In situ self-catalyzed formation of carbon nanotube wrapped and amorphous nanocarbon shell coated LiFePO₄ microclew for high-power lithium ion batteries, *Carbon.*, 2023, **203**, 661-670.
2. C. Juare-yescas, G. Ramos-Sánchez, I. González, Influence of reduced graphene oxides (rGO) at different reduction stages as conductive additive in Li-ion batteries, *Journal of Solid State Electrochemistry.*, 2018, **22**, 3225-3233.
3. T.F. Liu, L. Zhao, J.S. Zhu, B. Wang, C.F. Guo and D.L. Wang, The composite electrode of LiFePO₄ cathode materials modified with exfoliated graphene from expanded graphite for high power Li-ion batteries, *Journal of Materials Chemistry A.*, 2014, **2**, 2822-2829.
4. H.F. Zhu, Y.S. Xie, S.F. Zou, B. Na, R. Zeng and S. Zhang, Morphology control of free-standing LiFePO₄-based composite membranes for advanced lithium-ion battery cathodes, *Energy Technology.*, 2022, **10**, 2101080.