All lignin converted graphene quantum dots / graphene nanosheet hetero-junction for high-rate and boosted specific capacitance supercapacitor

Zheyuan Ding, Xiuwen Mei and Xiluan Wang *

Beijing Key Laboratory of Lignocellulosic Chemistry, Beijing Forestry University, Beijing, 100083, P. R. China

***Corresponding author. Tel: +86-10-62336903. E-mail: wangxiluan@bjfu.edu.cn**

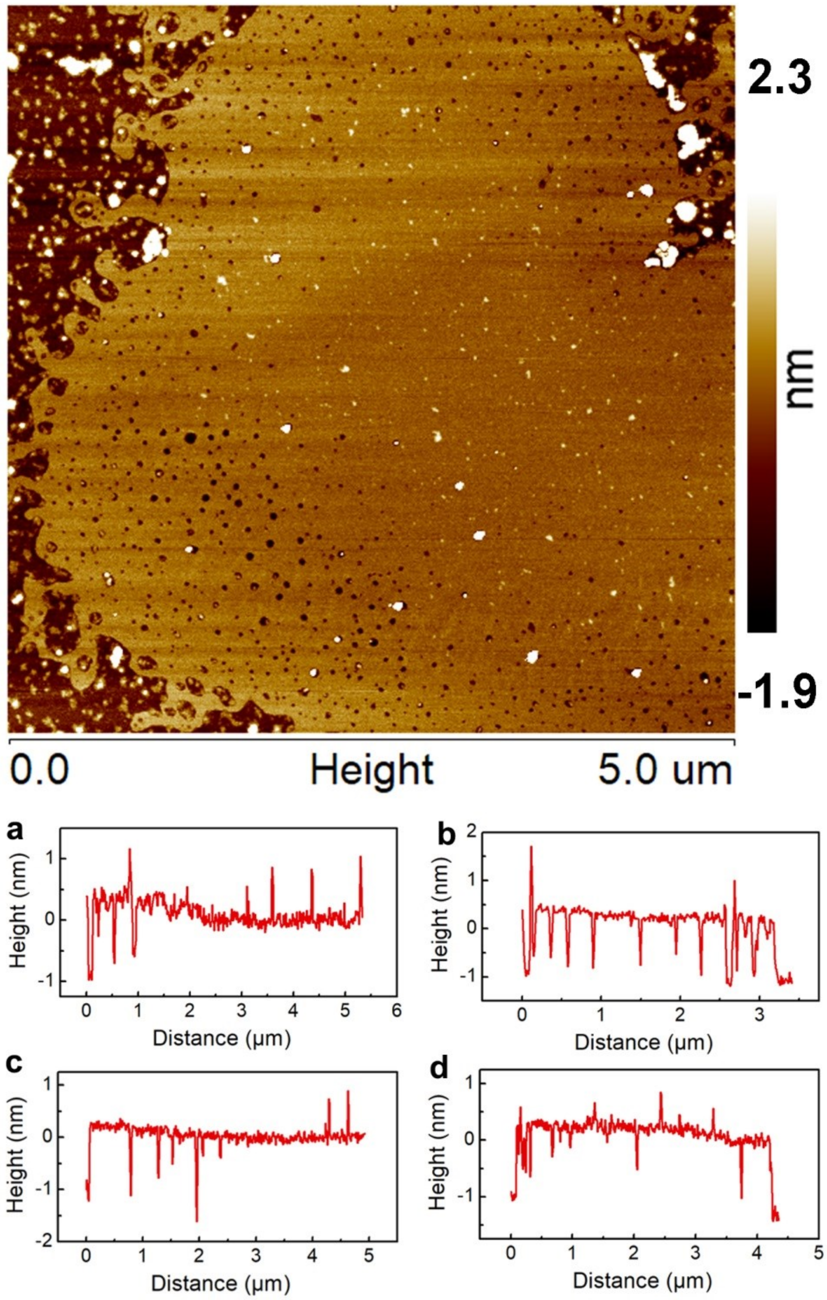

Fig. S1 The enlarged AFM figure of GQDs/Gr in Fig.1 (a-d) AFM profile of GQDs/BL-G within different directions (randomly chosen), indicative of the GQDs located on the porous graphene.

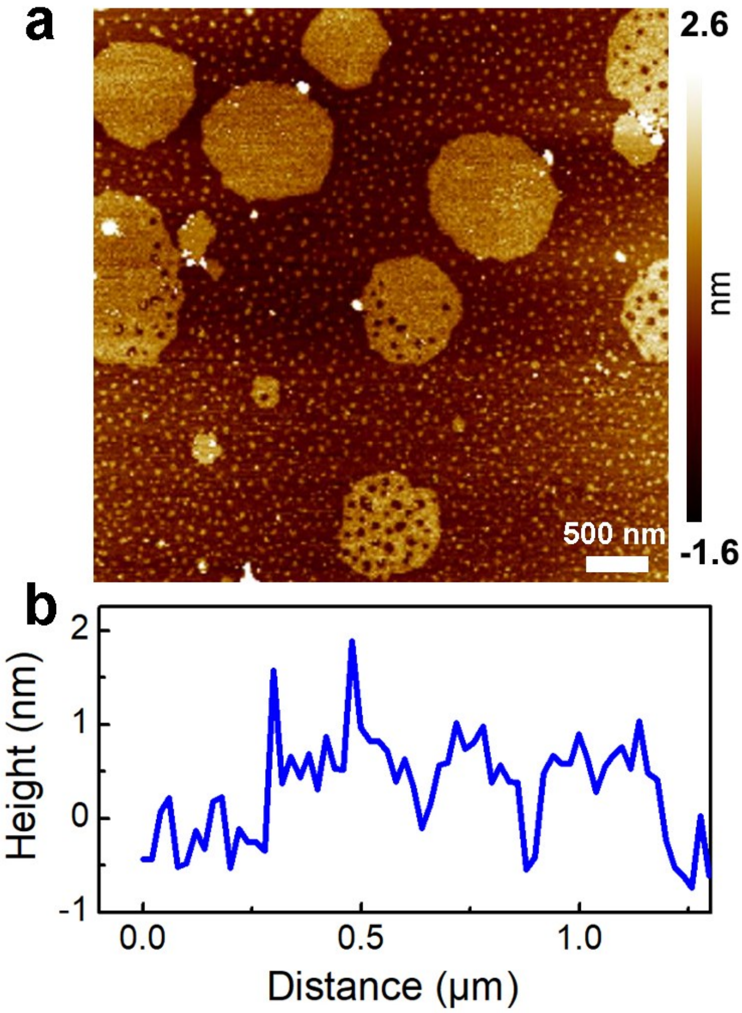

Fig. S2 (a) AFM image and (b) corresponding profile of GQDs/Gr.

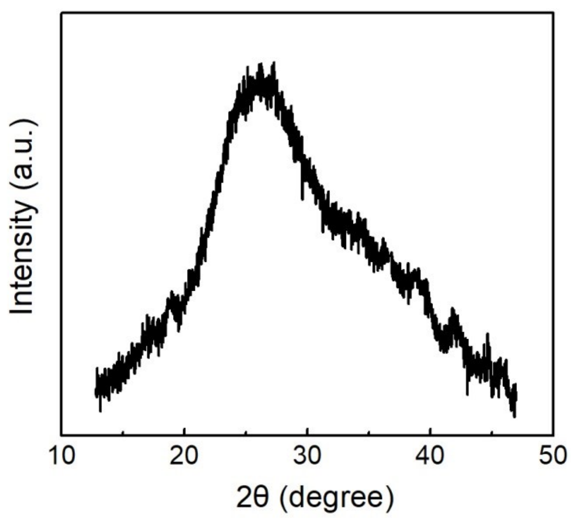

Fig. S3 The XRD pattern of GQDs/Gr.

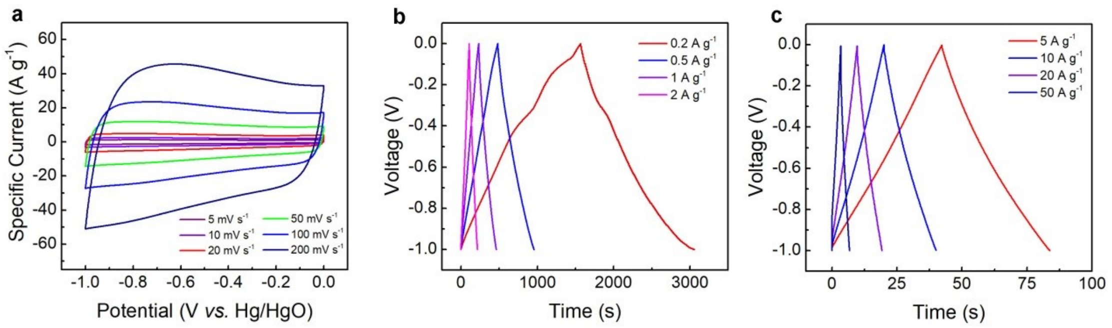

Fig. S4 (a) CV curve at scan rate from 5-200 mV s^{-1} (b-c) Galvanostatic charge/discharge curves under different current densities ranging from 0.2-50 A g^{-1}

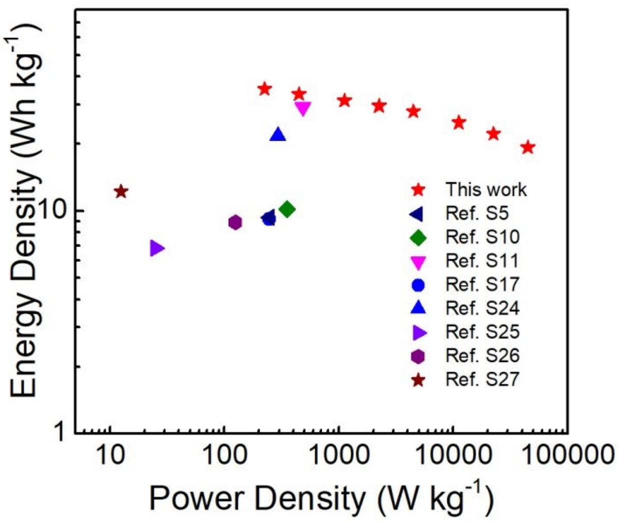

Fig. S5 (a) Energy density and power density of GQDs/Gr (Power density of 225 W kg^{-1} and energy density of 35.1 Wh kg^{-1}) compared with other biomass based supercapacitor

Table S1. Electrochemical performance of biomass-based supercapacitors.

Product	Resources	Specific capacitance (F g^{-1}) and Cycling Stability (%)	Relaxation time constant (τ0)	Conductivity Resistance (Ω)	Ref.
GQDs/Gr hetero-junction	**Lignin**	**404.6 F g^{-1} (0.1 A g^{-1}) 97 % (10,000 cycles)**	**0.3 s**	0.344	**This work**
Activated Carbon	Lignin	102.3 F g^{-1}(1 A g^{-1}) Not given	1.25 s	0.391	S1

carbon fiber	Lignin	155 F g^{-1} (0.1 A g^{-1}) 94%(6,000 cycles)	-	-	S2
Electrospun carbon fiber	Lignin	267.32 F g^{-1} (5 A g^{-1}) 96.7%(5,000 cycles)	-	-	S3
Porous carbons	Lignin	208 F g^{-1} (0.1 A g^{-1}) 96%(1500 cycles)	-	~1.6	S4
Porous carbons	Lignin and melamine	337 F g^{-1} (0.5 A g^{-1}) 98% (3000 cycles)	-	0.6	S5
Lignosulfonate/ Graphene	Lignosulfonate and GO	408 F g^{-1} (1 A g^{-1}) 84% (10,000 cycles)	0.56 s	0.4	S6
Porous carbon nanospheres	Resorcinol and formaldehyde resin	402.5 F g^{-1} (1 A g^{-1}) 96% (5,000 cycles)	3 s	-	S7
Porous nitrogen-doped carbon	lignin-derived byproduct	312 F g^{-1} (1 A g^{-1}) 98 % (20,000 cycles)	0.49 s	0.29	S8
N,S-codoped porous carbon nanosheets	willow catkin	298 F g^{-1} (0.5 A g^{-1}) 98% (10,000 cycles)	4.54 s	0.6	S9
porous carbon nanosheet	Soybean milk powder	240.7 F g^{-1} (1 A g^{-1}) 89.3% (5000 cycles)	~1 s	0.6	S10
1D carbon nanobelts	Tofu	262 F g^{-1} (0.5 A g^{-1}) 102% (10,000 cycles)	0.9 s	0.3	S11
Activated carbon	Bark	155 F g^{-1} (0.5 A g^{-1}) 96% (10,000 cycles)	1.62 s	0.9	S12
Nitrogen-doped ginger straw carbon	straw	122 F g^{-1} (0.5 A g^{-1}) 82.7% (10,000 cycles)	2.6 s	5.4	S13
Sheet-like porous carbon	Walnut shell	330 F g^{-1} (0.1 A g^{-1}) 95 % (10,000 cycles)	0.25 s	-	S14

Graphene-like Porous Active Carbon	Lotus	340 F g^{-1} (0.5 A g^{-1}) 98% (10,000 cycles)	-	0.45	S15
vertically aligned graphene nanosheet arrays	Bark	398 F g^{-1} (0.5 A g^{-1}) 96.3% (10,000 cycles)	0.59 s	0.36	S16

Table S2. Electrochemical performance of GQDs strategy modified carbon -based supercapacitors.

Product	Resources	Specific capacitance (F g^{-1})	Relaxation time constant (τ0)	Ref.
GQDs/Gr hetero-junction	**Lignin**	**404.6 F g^{-1} (0.1 A g^{-1})**	**0.3 s**	**This work**
GQDs/Porous carbon	Pluronic	315 F g^{-1} (1 A g^{-1})	5.62 s	S17
GQDs/Carbon nanofiber	PAN	335 F g^{-1} (1 A g^{-1})	0.44 s	S18
GQDs/Microporous carbons	Coal	270 F g^{-1} (0.1 A g^{-1})	16 s	S19
GQDs/Porous carbon nanosheets	Coal	230 F g^{-1} (1 A g^{-1})	-	S20
GQDs/Activated Carbon	Glucosamine	388 F g^{-1} (1 A g^{-1})	0.68 s	S21
CDs/ graphene	Citric acid	338 F g^{-1} (1 A g^{-1})	-	S22
CDs/ graphene oxide hydrogel	Glucose and GO	264 F g^{-1} (1 A g^{-1})	-	S23

Supporting References

S1. D. Saha, Y. Li, Z. Bi, J. Chen, J. K. Keum, D. K. Hensley, H. A. Grappe, H. M. Meyer III, S. Dai and M. P. Paranthaman, *Langmuir*, 2014, **30**, 900-910.

S2. P. Schlee, O. Hosseinaei, D. Baker, A. Landmér, P. Tomani, M. J. Mostazo-López, D. Cazorla-Amorós, S. Herou and M.-M. Titirici, *Carbon*, 2019, **145**, 470-480.

S3. Z. Dai, P.-G. Ren, Y.-L. Jin, H. Zhang, F. Ren and Q. Zhang, *Journal of Power Sources*, 2019, **437**, 226937.

S4. H. Li, D. Yuan, C. Tang, S. Wang, J. Sun, Z. Li, T. Tang, F. Wang, H. Gong and C. He, *Carbon*,

2016, **100**, 151-157.
S5. L. Zhu, F. Shen, R. L. Smith, L. Yan, L. Li and X. Qi, *Chemical Engineering Journal*, 2017, **316**, 770-777.
S6. F. Li, X. Wang and R. Sun, *Journal of Materials Chemistry A*, 2017, **5**, 20643-20650.
S7. B. Chang, Y. Guo, Y. Li, H. Yin, S. Zhang, B. Yang and X. Dong, *Journal of Materials Chemistry A*, 2015, **3**, 9565-9577.
S8. L. Zhang, T. You, T. Zhou, X. Zhou and F. Xu, *ACS applied materials & interfaces*, 2016, **8**, 13918-13925.
S9. Y. Li, G. Wang, T. Wei, Z. Fan and P. Yan, *Nano Energy*, 2016, **19**, 165-175.
S10. M. Chen, D. Yu, X. Zheng and X. Dong, *Journal of Energy Storage*, 2019, **21**, 105-112.
S11. T. Ouyang, K. Cheng, F. Yang, L. Zhou, K. Zhu, K. Ye, G. Wang and D. Cao, *Journal of Materials Chemistry A*, 2017.
S12. N. Yadav and S. Hashmi, *Sustainable Energy & Fuels*, 2020, 1730-1746.
S13. Y. Zheng, H. Wang, S. Sun, G. Lu, H. Liu, M. Huang, J. Shi, W. Liu and H. Li, *Sustainable Energy & Fuels*, 2020.
S14. T. Shang, Y. Xu, P. Li, J. Han, Z. Wu, Y. Tao and Q.-H. Yang, *Nano Energy*, 2020, **70**, 104531.
S15. S. Y. Lu, M. Jin, Y. Zhang, Y. B. Niu, J. C. Gao and C. M. Li, *Advanced Energy Materials*, 2017, 1702545.
S16. Z. Sun, M. Zheng, H. Hu, H. Dong, Y. Liang, Y. Xiao, B. Lei and Y. Liu, *Chemical Engineering Journal*, 2018, **336**, 550-561.
S17. W. Tian, J. Zhu, Y. Dong, J. Zhao, J. Li, N. Guo, H. Lin, S. Zhang and D. Jia, *Carbon*, 2020, **161**, 89-96.
S18. J. Zhao, J. Zhu, Y. Li, L. Wang, Y. Dong, Z. Jiang, C. Fan, Y. Cao, R. Sheng and A. Liu, *ACS Applied Materials & Interfaces*, 2020, **12**, 11669–11678.
S19. S. Zhang, J. Zhu, Y. Qing, L. Wang, J. Zhao, J. Li, W. Tian, D. Jia and Z. Fan, *Advanced Functional Materials*, 2018, **28**, 1805898.
S20. S. Zhang, J. Zhu, Y. Qing, C. Fan, L. Wang, Y. Huang, R. Sheng, Y. Guo, T. Wang and Y. Pan, *Materials today energy*, 2017, **6**, 36-45.
S21. Y. Qing, Y. Jiang, H. Lin, L. Wang, A. Liu, Y. Cao, R. Sheng, Y. Guo, C. Fan and S. Zhang, *Journal of Materials Chemistry A*, 2019, **7**, 6021-6027.
S22. G. Yuan, X. Zhao, Y. Liang, L. Peng, H. Dong, Y. Xiao, C. Hu, H. Hu, Y. Liu and M. Zheng, *Journal of Colloid and Interface Science*, 2019, **536**, 628–637.
S23. H. Feng, P. Xie, S. Xue, L. Li, X. Hou, Z. Liu, D. Wu, L. Wang and P. K. Chu, *Journal of Electroanalytical Chemistry*, 2018, **808**, 321-328.
S24. V. Sahu, S. Grover, G. Singh and R. K. Sharma, *RSC Advances*, 2016, **6**, 35014-35023.
S25. P. Hao, Z. Zhao, Y. Leng, J. Tian, Y. Sang, R. I. Boughton, C. P. Wong, H. Liu and B. Yang, *Nano Energy*, 2015, **15**, 9-23.
S26. M. S. Balathanigaimani, W.-G. Shim, M.-J. Lee, C. Kim, J.-W. Lee and H. Moon, *Electrochemistry Communications*, 2008, **10**, 868-871.
S27. G. Zhao, C. Chen, D. Yu, L. Sun, C. Yang, H. Zhang, Y. Sun, F. Besenbacher and M. Yu, *Nano Energy*, 2018, **47**, 547-555.