# Supplementary Information

## A hierarchical porous carbon derived from gas-exfoliation activation of lignin for high-energy lithium-ion batteries

Yuebin Xi, [a, d] Si Huang, [a, b] Dongjie Yang, *[a, b] Xueqing Qiu, * [a, c] Huajian Su, [a, b] Conghua Yi [a, b] and Qiong Li [a, b]

*[a.] School of Chemistry and Chemical Engineering, South China University of Technology, Wushan Road 381, Guangzhou 510640, China*
*[b.] Guangdong Green Fine Chemical Product Engineering Technology Research and Development Center, Guangzhou 510640, China*
*[c.] School of Chemical Engineering and Light Industry, Guangdong University of Technology, Waihuan Xi Road 100, Guangzhou 510006, China*
*[d.] State Key Laboratory of Biobased Material and Green Papermaking, Key Laboratory of Pulp and Paper Science and Technology of Ministry of Education, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250353, China*
***Corresponding Authors***
** E-mail: cedjyang@scut.edu.cn (D. Y.)*
** E-mail: cexqqiu@scut.edu.cn (X. Q.)*

**The specific purification process is as follows:**

Dissolving 200 g of bio-refinery residue in sodium hydroxide solution and stirred at 70 ℃ mix for 2 h, and ensure the solution pH ≥ 12. After the lignin completely dissolved, the insoluble impurities was filtered and removed, and the filtrate was collected. Then, adding 50 wt% sulfuric acid solution to the filtrate while stirring at 65 ℃, adjusting the pH value of the solution to 2 with continue stirring for 2 h until lignin was aggregated and precipitated. After standing for more than 24 h, the purified lignin was obtained by filtration, washing and drying after the lignin has settled completely. Last, it was packaged and preserved for later experiment.

**Test method of EHL purity：**

A two-stage acid hydrolysis procedure was employed to hydrolyze the milled EHL and purity EHL substrates. The supernatant after filtration through filter paper was used for carbohydrate analysis by using high-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD). EHL retained on the filter paper was quantified gravimetrically after drying. The typical standard deviation of the chemical composition analysis was approximately 0.3% (X. Luo, R. Gleisner, S. Tian, J. Negron, W. Zhu, E. Horn, X. J. Pan, J.Y. Zhu, *Ind. Eng. Chem. Res*, 2010, 49, 8258-8266; C. Cai, X. Qiu, X. Lin, H. Lou, Y. Pang, D. Yang, S. Chen, K. Cai, *Bioresource Technology*, 2016, 216, 968-975.).

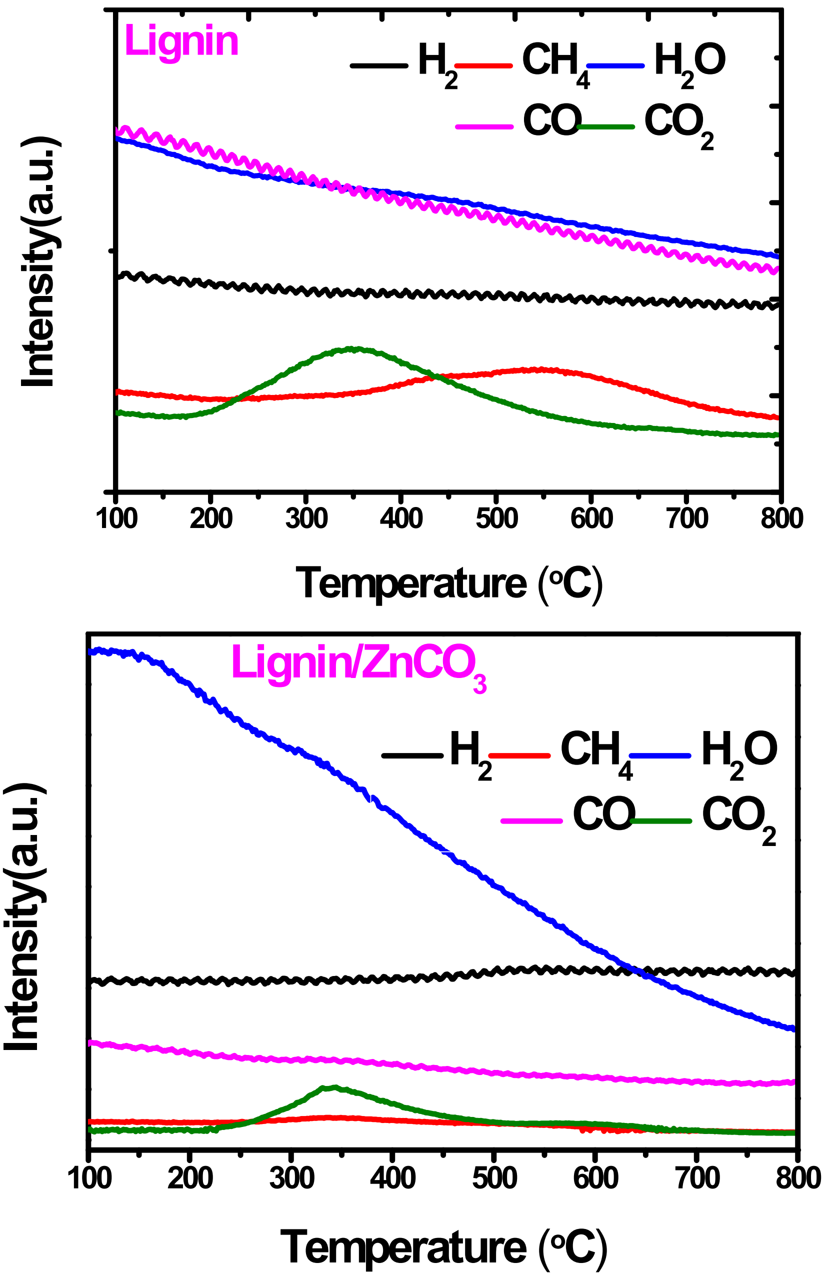


Fig. S1 MS curve of lignin and lignin/$ZnCO_3$ mixture pyrolyzed in the Ar atmosphere

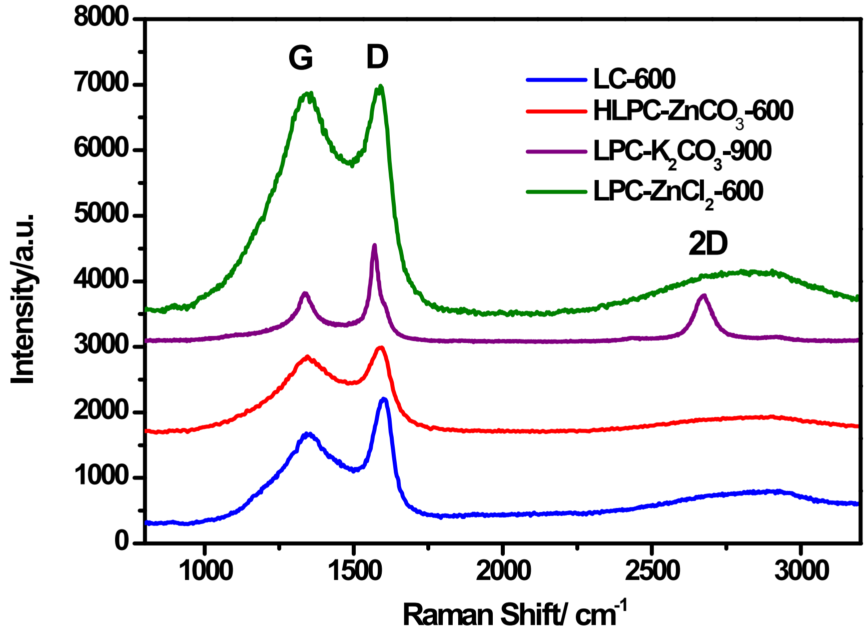


Fig. S2 Raman spectrum of LC-600, HLPC-$ZnCO_3$-600, LPC-$K_2CO_3$-900 and LPC-$ZnCl_2$-600

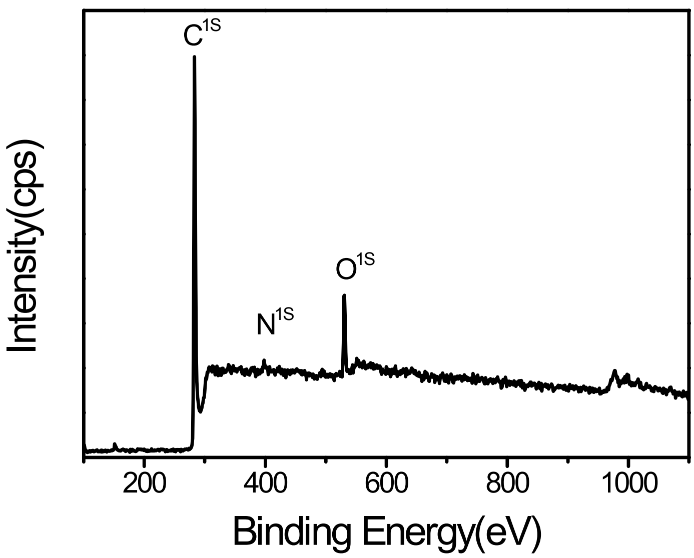


Fig. S3 XPS spectrum of HLPC-$ZnCO_3$-600 and the atomic contents of C, O and N are 95.08%, 4.65% and 0.27%

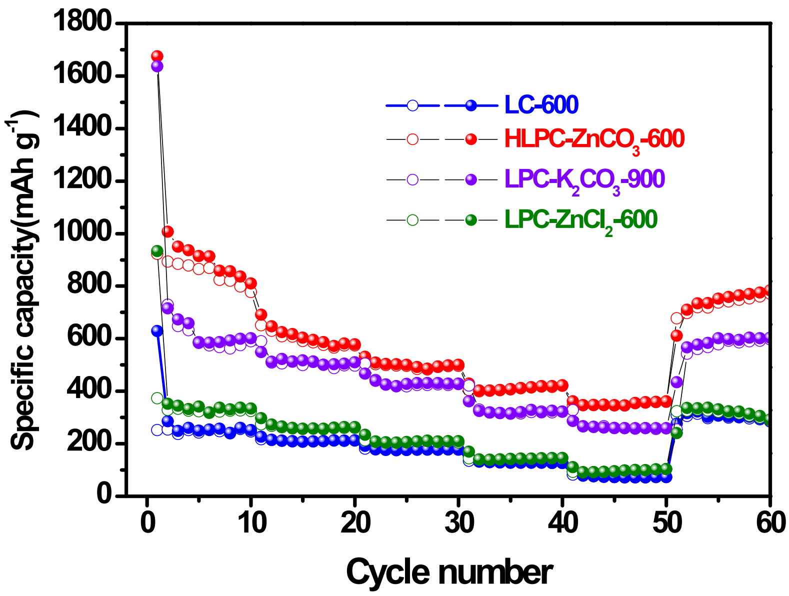


Fig. S4 the rate performance of LC-600, HLPC-$ZnCO_3$-600, LPC-$K_2CO_3$-900 and LPC-$ZnCl_2$-600

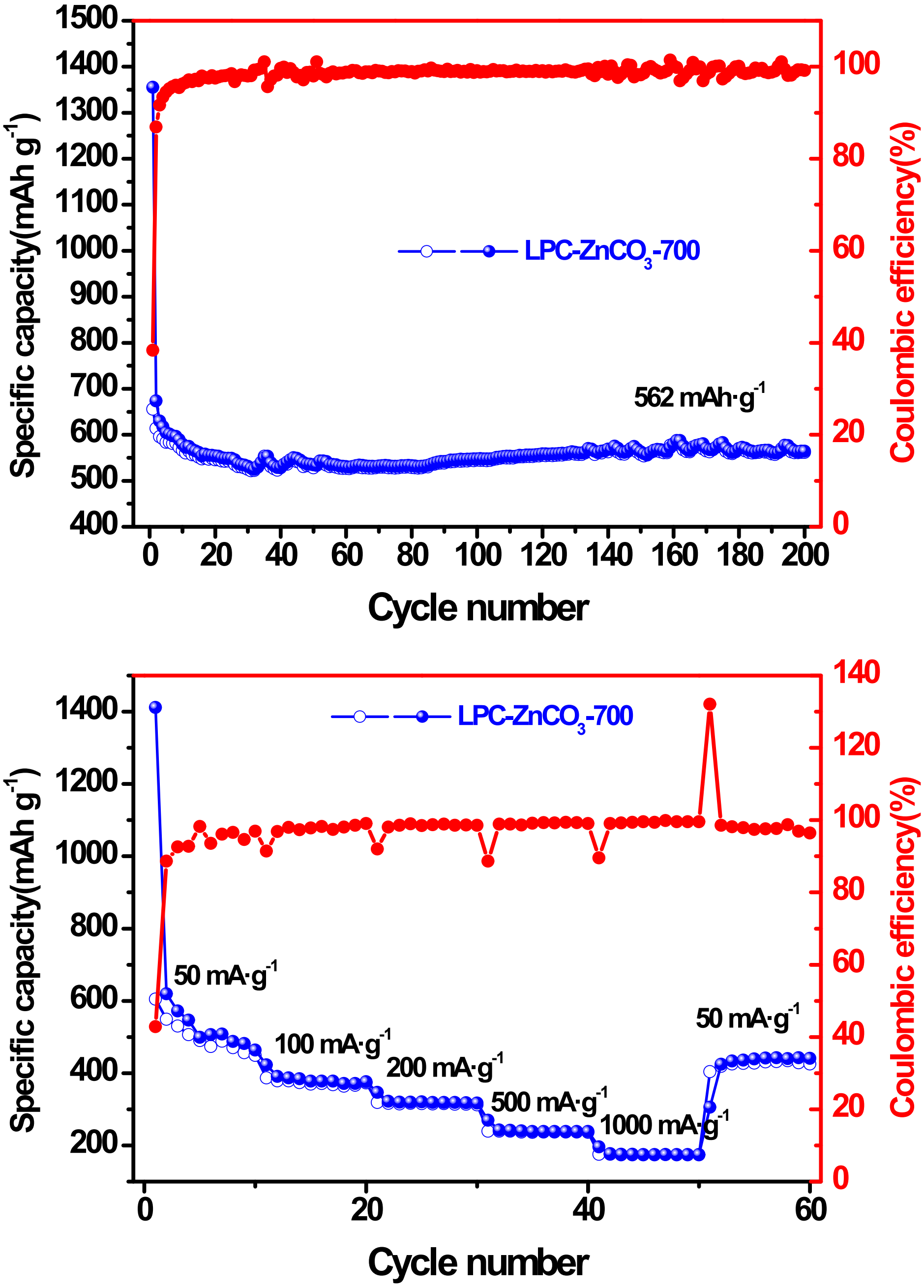


Fig. S5 the cyclic performance and rate performance of LPC-$ZnCO_3$-700

Table S1 Microstructure parameters of LPC obtained under different conditions

| **Samples** | **$S_{BET}$ [a] ($m^2$ $g^{-1}$)** | **$V_{total}$ [b] ($cm^3$ $g^{-1}$)** | **$V_{meso}$ [c] ($cm^3$ $g^{-1}$)** | ***$R_{meso}$* [d] (%)** | **$I_D/I_G$** |
|---|---|---|---|---|---|
| LC-600 | 12 | 0.02 | -- | --- | 1.20 |
| HLPC-$ZnCO_3$-600 | 531 | 0.42 | 0.28 | 66.7 | 0.89 |
| LPC-$K_2CO_3$-900 | 2300 | 0.48 | 0.13 | 27.0 | 0.72 |
| LPC-$ZnCl_2$-600 | 971 | 0.24 | 0.05 | 20.8 | 0.89 |

a. $S_{BET:}$ BET surface area.

b. $V_{total}$: Total pore volume.

c. $V_{meso}$: Pore volume of mesopore.

d. $R_{meso}$: Pore volume percent of mesopore.

**Table S2** Microstructure parameter of LPC obtained at different temperature by $ZnCO_3$ activation

| **Samples** | **$S_{BET}$ ($m^2 \cdot g^{-1}$)** | **$V_{total}$ ($cm^3 \cdot g^{-1}$)** | **$V_{meso}$ ($cm^3 \cdot g^{-1}$)** | **$V_{mic}$ [a] ($cm^3 \cdot g^{-1}$)** | **$R_{meso}$ (%)** | **$R_{mic}$ [b] (%)** |
|---|---|---|---|---|---|---|
| Lignin/$ZnCO_3$ | 8.4 | - | - | - | - | - |
| LPC-$ZnCO_3$-250 | 5.3 | - | - | - | - | - |
| LPC-$ZnCO_3$-400 | 51.0 | 0.08 | 0.01 | 0.02 | 12.5 | 25.0 |
| LPC-$ZnCO_3$-500 | 109 | 0.11 | 0.06 | 0.02 | 54.5 | 18.2 |
| HLPC-$ZnCO_3$-600 | 531 | 0.42 | 0.28 | 0.06 | 66.7 | 14.3 |
| LPC-$ZnCO_3$-700 | 677 | 0.78 | 0.66 | 0.05 | 84.6 | 6.4 |

a. $V_{mic}$: Pore volume of micropore.

b. $R_{mic}$: Pore volume percent of micropore.

**Table S3** Comparison of lithium storage performance of carbon materials obtained from different carbon sources

| Carbon source | Activator | Carbonization (°C) | SBET ($m^2 \cdot g^{-1}$) | Testing condition | $Q_V$ [a] ($mAh \cdot cm^{-3}$) | $Q_d$ [b] ($mAh \cdot g^{-1}$) | Ref |
|---|---|---|---|---|---|---|---|
| **EHL** | **$ZnCO_3$** | **600** | **531** | **200 $mA \cdot g^{-1}$** | **733** | **545** | **This work** |
| Alkali lignin (Ⅰ) | KOH | 700 | 907 | 200 $mA \cdot g^{-1}$ | 276 | 470 | 1 |
| Corn stalks lignin | - | 800 | 188 | 2 C | 634 | 222 | 2 |
| Alkali lignin (Ⅱ) | - | 750 | 419 | 60 $mA \cdot g^{-1}$ | 245 | 194 | 3 |
| Organosolv lignin | - | 900 | - | 30 $mA \cdot g^{-1}$ | - | 576 | 4 |
| Sodium lignosulfonate (Ⅰ) | - | 700 | 296 | 100 $mA \cdot g^{-1}$ | 545 | 431 | 5 |
| Sodium lignosulfonate(Ⅱ) | - | 800 | 867 | 200 $mA \cdot g^{-1}$ | 429 | 700 | 6 |
| Hydrolysis lignin | - | Room temperature | - | 25 $mA/cm^2$ | - | 450 | 7 |
| Sodium lignosulfonate (Ⅲ) | - | 900 | ＜261.9 | 0.2C | 302 | 149 | 8 |
| Alkali lignin (III) | - | 1000 | - | 0.1 | - | 335 | 9 |
| Graphene | KOH | 850 | 770 | 200 $mA \cdot g^{-1}$ | 311 | 180 | 10 |
| Silk | $ZnCl_2$ | 900 | 2494 | 1C | 298 | 1400 | 11 |
| sheep bone | - | 1100 | 2058 | 1 $A \cdot g^{-1}$ | 124 | 480 | 12 |
| Duckweed | - | 800 | 534 | 100 $mA \cdot g^{-1}$ | 1070 | 1070 | 13 |
| Broad beans | KOH | 650 | 655 | 1C | 212 | 261 | 14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| D-Glucose | | 1000 | 412 | 1C | 402 | 310 | 15 |
| Sweet potato | | 850 | 79 | 200 mA·$g^{-1}$ | - | 370 | 16 |
| Rice husk | | 1000 | 243 | 200 mA·$g^{-1}$ | 895 | 403 | 17 |
| Bacterial nanocellulose | | 900 | 670 | 75 mA·$g^{-1}$ | 306 | 386 | 18 |
| Coir pith | KOH | 850 | 2500 | 100 mA·$g^{-1}$ | 178 | 837 | 19 |
| g-$C_3N_4$@RGO | KOH | 550 | 215 | 500 mA·$g^{-1}$ | 2221 | 899.3 | 20 |

a. $Q_v$: volume specific capacity, which obtained according to the conversion of the specific surface area conversion.

b. $Q_d$: discharge mass specific capacity.

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