Electronic Supplementary Material

High-yield production of porous carbon spheres derived from enzymatic hydrolysis lignin for zinc ion hybrid capacitors

Tao Huang[1], Xihong Zu[1], Jianhui Ma[1], Wenbin Jian[1], Xueqing Qiu (✉)[1,3], Wenli Zhang (✉)[1,2,3]

1 Guangdong Provincial Key Laboratory of Plant Resources Biorefinery, School of Chemical Engineering and Light Industry, Guangdong University of Technology, Guangzhou 510006, China

2 School of Advanced Manufacturing, Guangdong University of Technology, Jieyang 522000, China

3 Jieyang Branch of Chemistry and Chemical Engineering Guangdong Laboratory (Rongjiang Laboratory), Jieyang 515200, China

E-mails: cexqqiu@scut.edu.cn (Qiu X); wlzhang@gdut.edu.cn; hiteur@163.com (Zhang W)

1. Supporting Experimental Section

1.1 Electrochemical measurements and calculations

All cyclic voltammetry (CV), galvanostatic charge-discharge (GCD) and electrochemical impedance spectra (EIS) measurements were conducted with Gamry interface 1010B electrochemical workstation. The EIS spectra were measured in the frequency range of 1000 kHz to 10 mHz with a voltage amplitude of 10 mV.

The specific gravimetric capacitances of electrode material (C_g, F g^{-1}) were calculated from the discharge curves of GCD in the three-electrode system:

$$C_g = \frac{I\Delta t}{Um} \quad \text{(S1)}$$

$$C_v = \frac{I\Delta t}{UV} \quad \text{(S2)}$$

where I is test current of GCD, Δt is the discharging time, U is the working voltage window, m is the mass of the electrode material and V is the volume of the electrode material.

The capacitive contribution was calculated from CV result. The equation is described as the following:

$$i = k_1 v + k_2 v^{\frac{1}{2}} \quad \text{(S3)}$$

$$\frac{i}{v^{\frac{1}{2}}} = k_1 v^{\frac{1}{2}} + k_2 \quad \text{(S4)}$$

where k_1v and $k_2v^{1/2}$ correspond to the current contributions from the capacitive contributions and diffusion-controlled processes.

Gravimetric energy density (E) and power density (P) were calculated according to the following equation:

$$E = \frac{I \int U dt}{m} \quad \text{(S5)}$$

$$P = \frac{E}{\Delta t} \quad \text{(S6)}$$

2. Supporting Figures

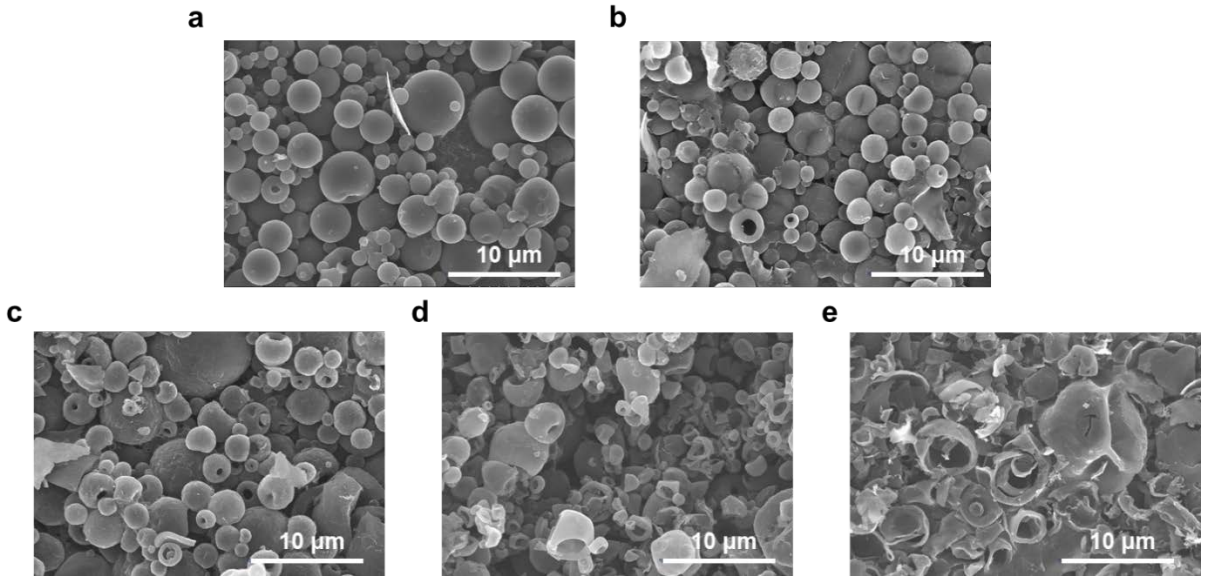

Figure S1. SEM image of (a) LPC-1-0.2; (b) LPC-1-0.5; (c) LPC-1-1; (d) LPC-1-2; (e) LPC-1-3.

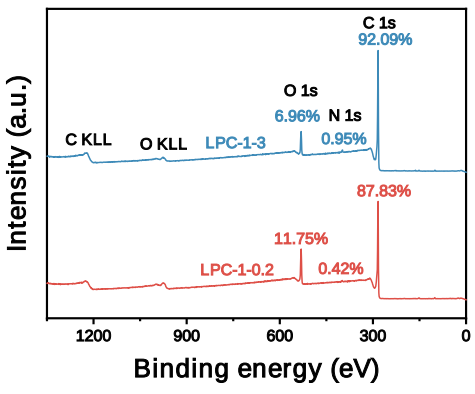

Figure S2. XPS survey spectra of LPC-1-0.2 and LPC-1-3.

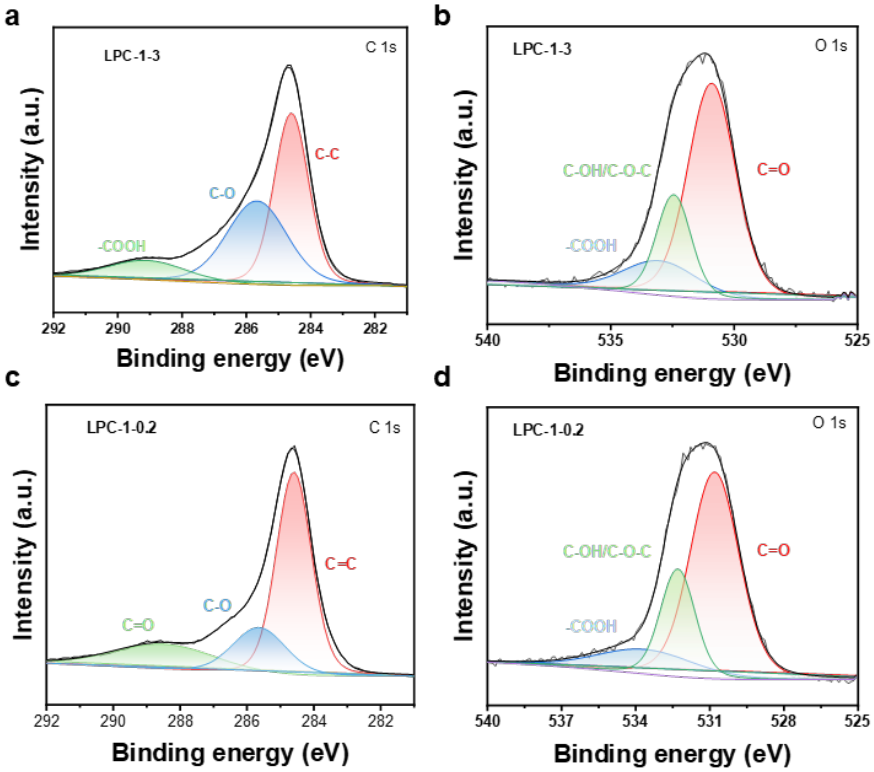

Figure S3. (a) XPS survey spectra of LPC-1-0.2 and LPC-1-3;(a, b) High-resolution C 1s and O 1s XPS spectra of the LPC-1-3; (c, d) High-resolution C 1s and O 1s XPS spectra of the LPC-1-0.2.

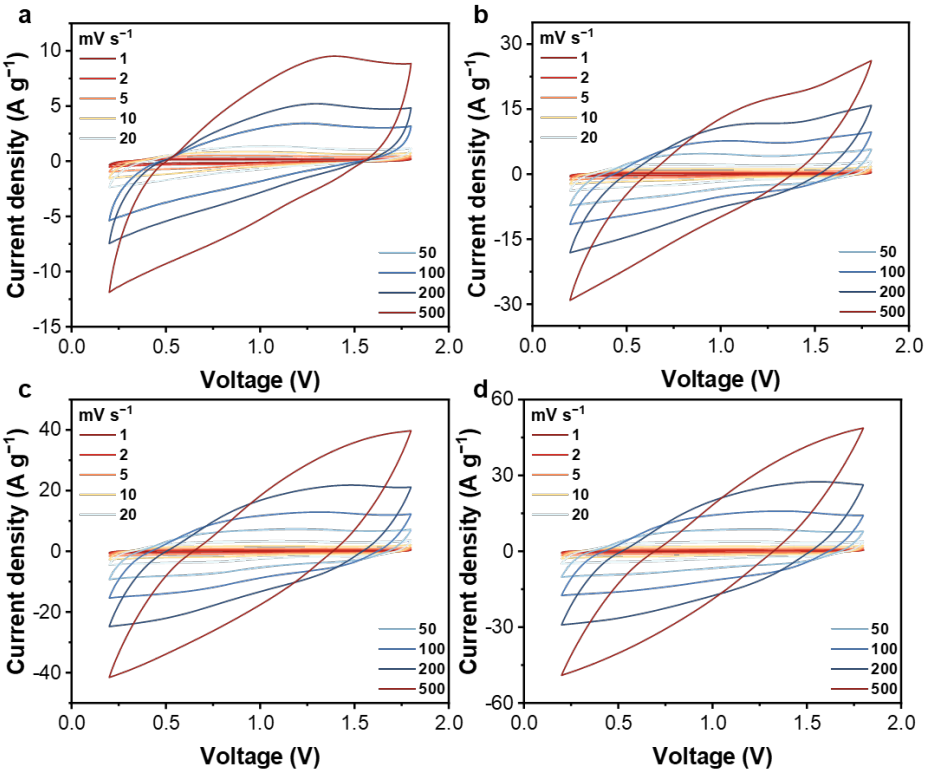

Figure S4. CV curves at different scan rates of (a) LPC-1-0.2, (b) LPC-1-0.5, (c) LPC-1-1, (d) LPC-1-2.

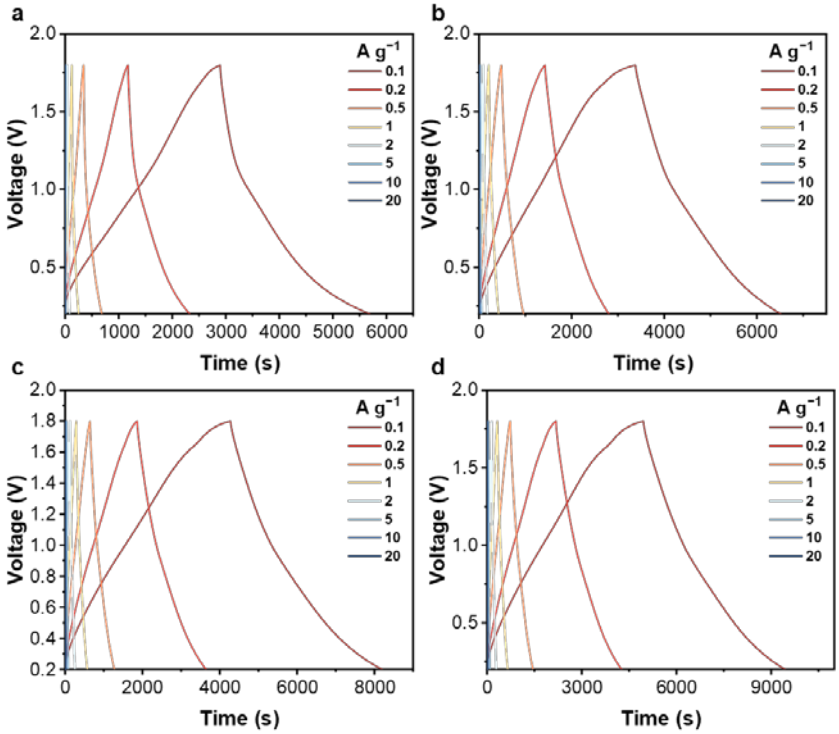

Figure S5. GCD curves at different current densities of (a) LPC-1-0.2, (b) LPC-1-0.5, (c) LPC-1-1, (d) LPC-1-2

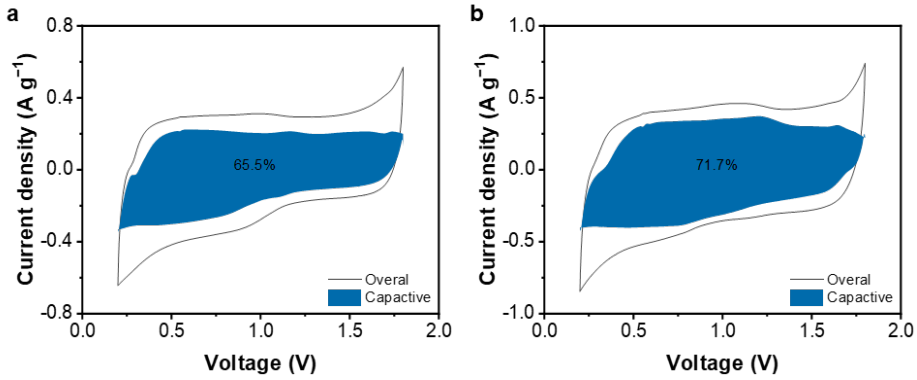

Figure S6. (a, b) Contribution of capacitance and diffusion-controlled charge at 2 mV s^{-1} of LPC-1-0.5 and LPC-1-2.

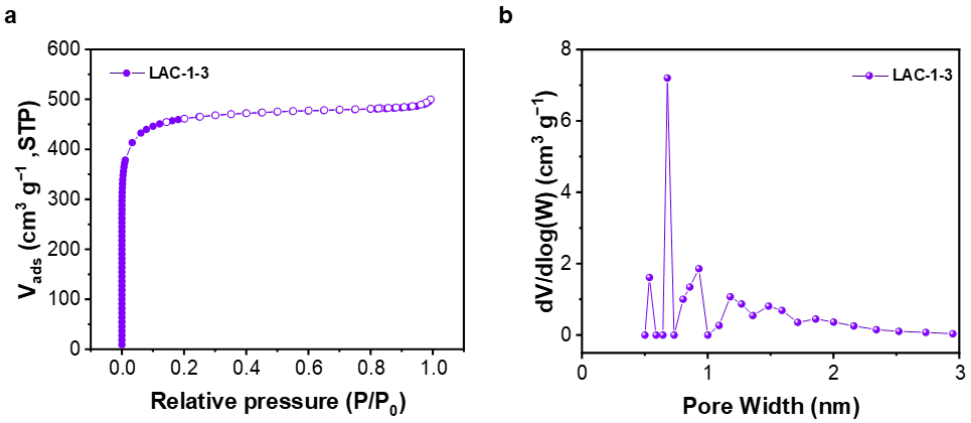

Figure S7. (a) Nitrogen adsorption–desorption isotherms of LAC-1-3; (b) Pore size distribution of LAC-1-3.

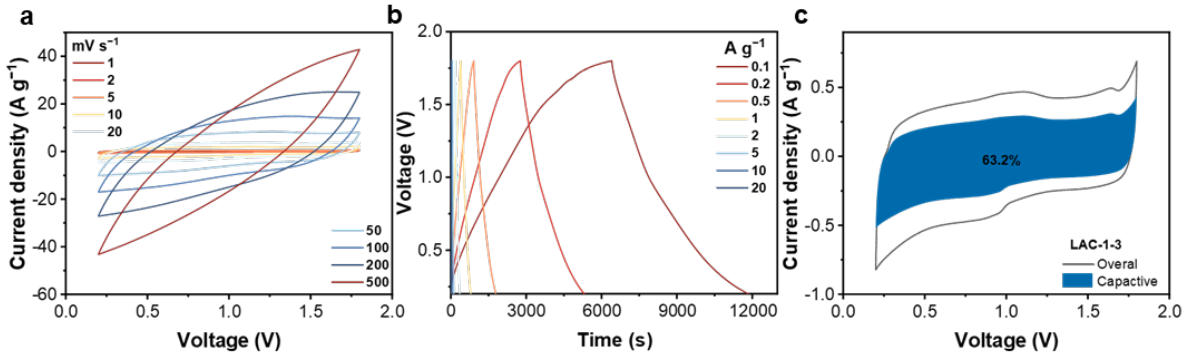

Figure S8. (a) CV curves at different scan rates of LAC-1-3; (b) GCD curves at different current densities of LAC-1-3; (c) Contribution of capacitance and diffusion-controlled charge at 2 mV s^{-1} of LAC-1-3.

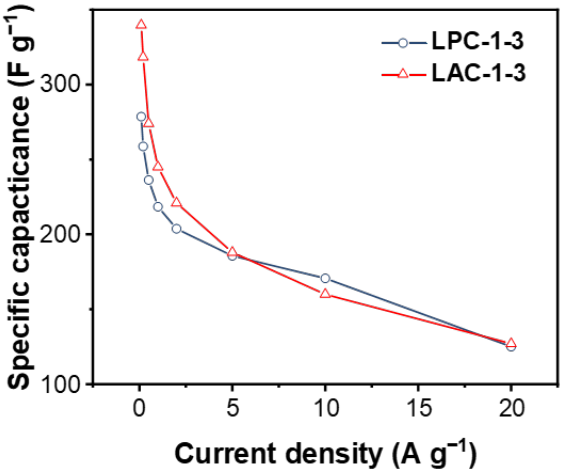

Figure S9. Charge/discharge rate performance of LPC-1-3, LAC-1-3.

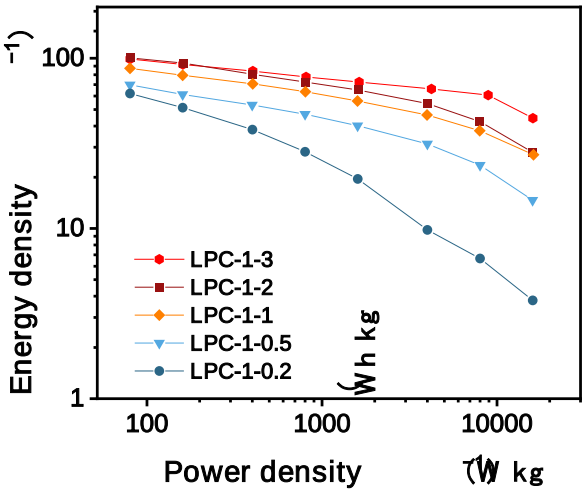

Figure S10. Ragone plot illustrating the relationship between energy density and power density.

3. Supporting Table

Table S1. The carbon yield of LPC

Sample	LPC-1-0.2	LPC-1-0.5	LPC-1-1	LPC-1-2	LPC-1-3
Carbon Yield (%)	41	31	32	28	22

The equation to calculate the carbon production yield of LPC is as follows:

$$\mathrm{LPC_{Yield}} = \frac{m(LPC)}{\mathrm{m(Lignin)}} \times 100\%$$

$\mathrm{m(LPC)_{Real}}$ was the actual weight of the pyrolysis product after acid and water washing, $m(Lignin)$ was the weight of the precursor before carbonization, $\mathrm{LPC_{Yield}}$ was the carbon production yield.

Table S2. Comparison of the rate of LPC electrodes

Current density	0.1	0.2	0.5	1	2	5	10	20	Capacity Retention
($A\ g^{-1}$)	Capacitance ($F\ g^{-1}$)								Rate (%)
LPC-1-0.2	174.7	144.1	107.2	79.4	55.1	27.6	18.8	10.6	6
LPC-1-0.5	196.3	172.4	149.4	131.9	113.1	88.3	66.2	41.3	21
LPC-1-1	245.7	223.3	199.1	178.9	157.8	130.6	105.6	76.3	31
LPC-1-2	282.7	263.6	226.5	203.9	182.9	152.2	119.4	78.7	28
LPC-1-3	278.6	258.8	236.3	218.5	203.8	185.7	170.7	125.1	45

Table S3. Comparison of the rate of LPC electrodes

Current density	0.1	0.2	0.5	1	2	5	10	20	Capacity Retention Rate (%)
($A\ g^{-1}$)	Capacitance ($F\ cm^{-3}$)								
LPC-1-0.2	597.1	492.5	366.4	271.4	188.3	94.3	64.3	36.2	6
LPC-1-0.5	613.4	538.8	466.9	412.2	353.4	275.9	206.9	129.1	21
LPC-1-1	815.8	741.4	661.1	594.0	523.9	433.6	350.6	253.3	31
LPC-1-2	938.7	875.2	752.1	677.0	607.3	505.4	396.4	261.3	28
LPC-1-3	925.0	859.3	784.6	725.5	676.7	616.6	566.8	415.4	45