Supporting Information

Biomass-derived B/N/P co-doped porous carbons as bifunctional materials for supercapacitors and sodium-ion batteries

Yanjiao Li,[a] Xufei Zou,[a] Shiqi Li,[a] Yingying Chen, *[ab] Guoxiu Wang,[b] Hongxun Yang,*[a] and Hao Tian*[b]

[a] School of Environmental and Chemical Engineering, Jiangsu University of Science and Technology, Zhenjiang 212003, Jiangsu, China

[b] Centre for Clean Energy Technology, School of Mathematical and Physical Sciences, Faculty of Science, University of Technology Sydney, Broadway, NSW 2007, Australia.

*Corresponding author.

Email: scyyh@just.edu.cn (Y. Chen); yhongxun@126.com (H. Yang); hao.tian@uts.edu.au (H. Tian)

Text S1

From the GCD results, the specific capacitance (Cs, F g^{-1}) of the three-electrode system was calculated according to the following equation S2 (Eq. S2) [1]:

$$C_s = \frac{I \times \Delta t}{m \times \Delta V} \quad \text{(S2)}$$

The single electrode specific capacitance of the whole symmetric supercapacitors was obtained by the equation S3 (Eq. S3) [1]:

$$C_{cell} = \frac{4 \times I \times \Delta t}{M \times \Delta V} \quad \text{(S3)}$$

In which two–electrode systems, the energy density (E, Wh kg^{-1}) and power density (P, W kg^{-1}) were calculated by the equations S4and S5(Eq. S4 and Eq. S5) [1]:

$$E = \frac{\Delta V^2 C_{cell}}{8 \times 3.6} \quad \text{(S4)}$$

$$P = \frac{3600 \times E}{\Delta t} \quad \text{(S5)}$$

Where Cs or C_{cell} (F g^{-1}) is the gravimetric specific capacitance of active materials, I (A) represent the constant discharging current, Δt (s) corresponds to the discharge time, M (g) is the total mass of the positive and negative electrodes and ΔV (V) is the voltage change within discharge process.

The interlayer distance (d_{002}) was calculated using the (002) graphite diffraction peak and Bragg Eq. (S6) [4]:

$$d_{002} = \frac{\lambda}{2sin\theta} \quad \text{(S6)}$$

where λ is the X–ray wavelength (0.154 nm) and θ is the scattering angle corresponding to the peak position.

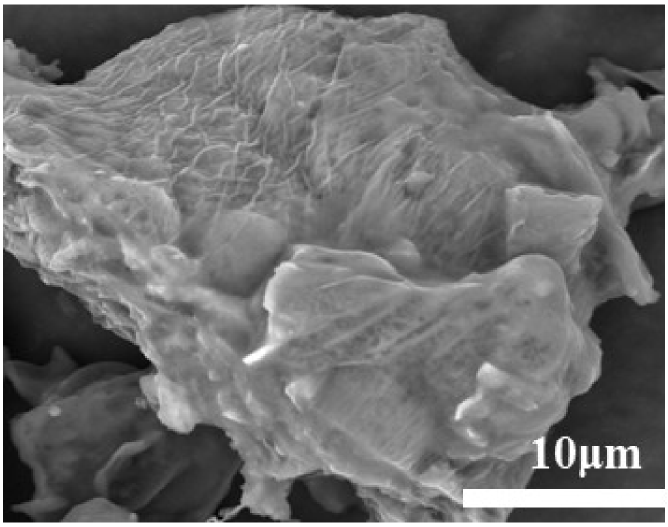

Fig. S1 The original SEM image of OP.

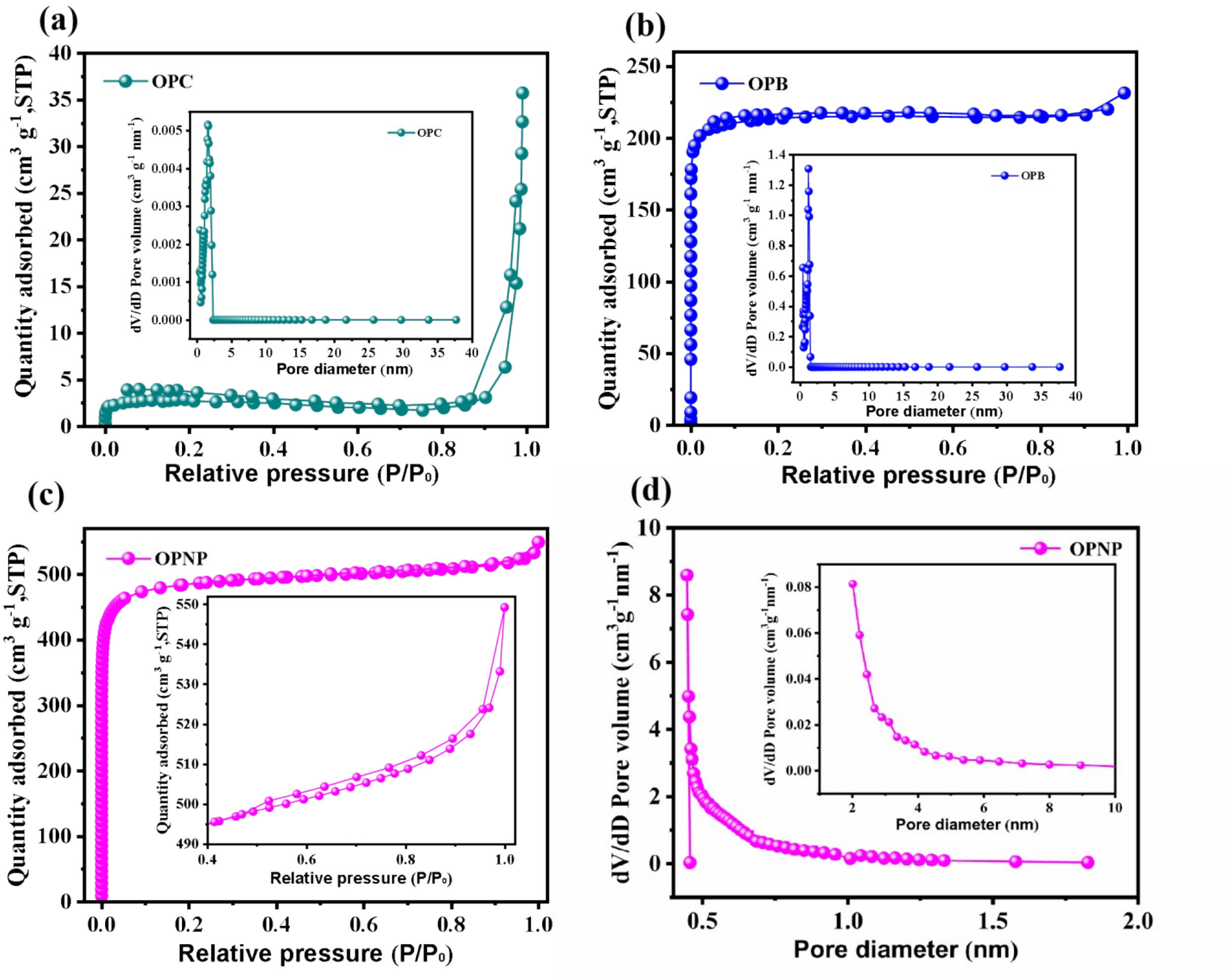

Fig. S2 (a) N_2 adsorption-desorption isotherms of OPC, inset: pore size distribution; (b) N_2 adsorption-desorption isotherms of OPB, inset: pore size distribution; (c) N_2 adsorption-desorption isotherms of OPNP, inset: partial amplification region; (d) the pore size distribution of OPNP.

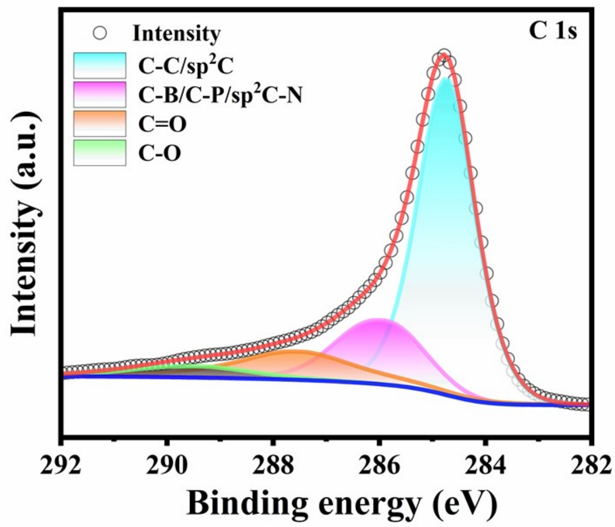

Fig. S3 C 1s high resolution spectra of OPBNP.

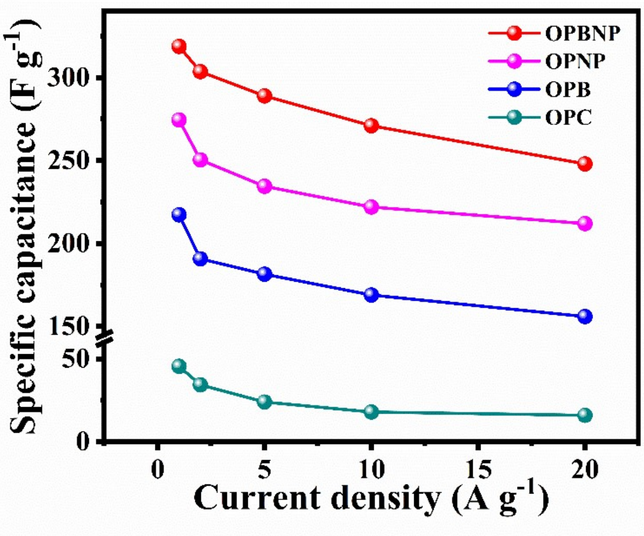

Fig. S4 The OPC, OPB, OPNP, OPBNP specific capacitance values at different current densities.

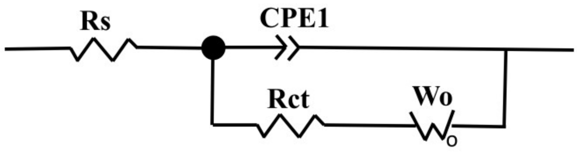

Fig. S5 Equivalent circuit diagram of electrodes.

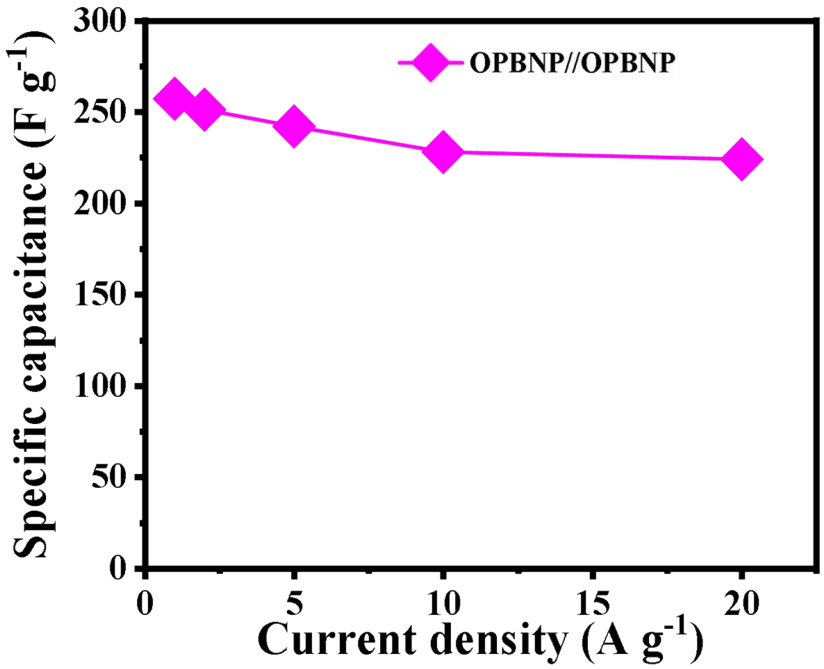

Fig. S6 Specific capacitance at different current densities.

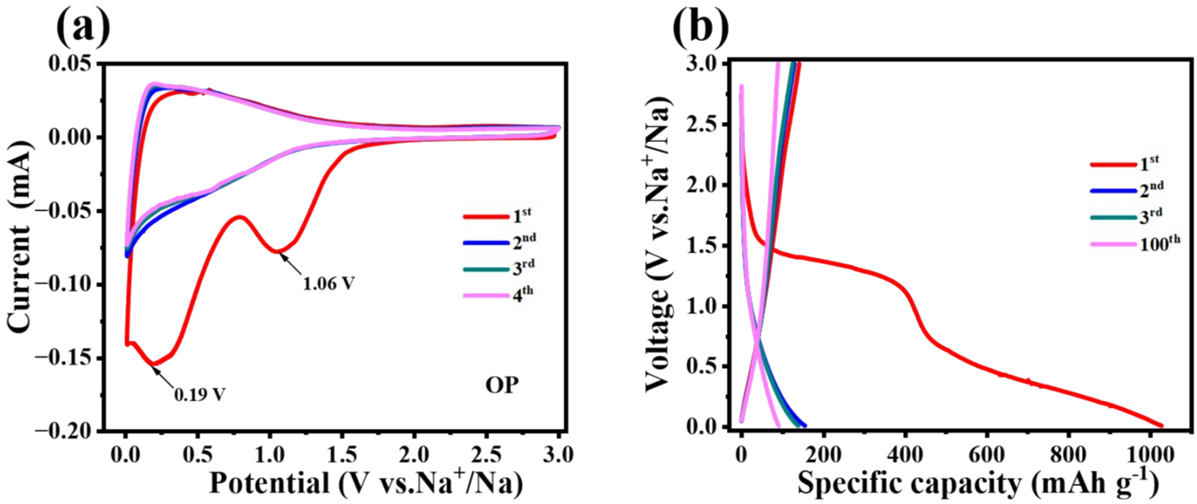

Fig. S7 CV curves of OPC electrodes (a) 0.1 mV s^{-1}; (b) The charge-discharge curves of the 1^{st}, 2^{nd}, 3^{rd} and 100^{th} cycles at 0.1 A g^{-1}.

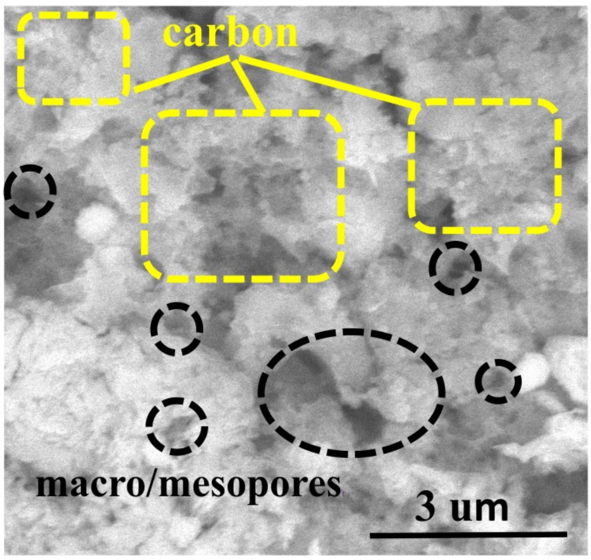

Fig. S8 SEM image of the OPBNP electrode after 1000 cycles at 1 A g^{-1} for SIBs.

Table S1 Results of charge-discharge specific capacitance and impedance parameters of three-electrode system at different current densities.

Current density (A g^{-1}))		Specific capacitance （F g^{-1}）			
		OPC	OPB	OPNP	OPBNP
1		45.5	217.3	274.5	318.8
2		34.4	190.8	250.4	303.6
5		24.0	181.5	234.5	289.0
10		18	169.0	222.0	271.0
20		16	156.0	212.0	248.0
Efficiency（%）		35.2	71.7	77.2	77.8
Impedance（Ω）	R_s	0.55	0.61	0.60	0.54
	R_{ct}	0.092	0.062	0.053	0.043

Table S2 Comparisons of specific capacitance (Cs) of nitrogen, phosphorus and other heteroatomic co–doped biomass–derived carbon.

Carbon source	Activation method	S_{BET} (m^2 g^{-1})	Cs (F g^{-1})	Measurement condition	Refs
Pomelo peel	Thermal + $(NH_4)_2HPO_4$	807	240	2 M KOH, 0.5 A g^{-1}	[5]
shrimp shell	H_3PO_4	726	260	6 M KOH, 0.05 A g^{-1}	[6]
Walnut shell	KOH+H_3PO_4	2583	332	6 M KOH, 1 A g^{-1}	[7]
Silkworm cocoon	Phytic acid	1247.2	317	1 M H_2SO_4, 1 A g^{-1}	[8]
Bacterial cellulose	$(NH_4)_2HPO_4$	731.9	232	6 M KOH, 1 A g^{-1}	[9]
Molasses	Ammonium polyphosphate	422.9	160	6 M KOH, 1 A g^{-1}	[10]
Tea leaves		129	158		
Duck weed	KOH	1636	315.2	6 M KOH, 1 A g^{-1}	[11]
Cicada molasses	KOH	1676	355	6 M KOH, 1 A g^{-1}	[12]
Orange peel	$(NH_4)_2HPO_4$ + Boric acid	1774.8	318.8	6 M KOH, 1 A g^{-1}	This work

Table S3 Comparisons of the electrochemical performances of biomass-derived hard carbon for SIBs.

Biomass precursor	Calcination temperature (℃)	current density ($A\ g^{-1}$)	Reversible capacity ($mA\ h\ g^{-1}$)	Rate ($A\ g^{-1}$)	Reversible capacity ($mA\ h\ g^{-1}$)	Refs
Coconut			270 (100 cycles)	–	–	[1]
Silk			273 (100 cycles)	–	–	
Walnut shell	1000	0.1	305 (200 cycles)	1	182 (1500 cycles)	[13]
Rice husk	1200	0.025	328.4 (100 cycles)	0.1	232.3 (400 cycles)	[14]
Gelatin	700	0.2	309 (200 cycles)	1	225 (2000 cycles)	[15]
medicine residue	800	0.1	801 (500 cycles)	5	402 (500 cycles)	[16]
crab shell	800	0.03	339.1 (1^{st})	0.5	132.4 (200 cycles)	[17]
Reed straw	1300	0.025	372.0 (1^{st})	0.1	283.8 (200 cycles)	[18]
Mushroom stalk	900	0.1	305 (10 cycles)	–	–	[19]
Cirsium setosum	700	0.1	268 (100 cycles)	1	198.6 (320 cycles)	[20]
Mango peel	800	0.1	358 (300 cycles)	2	155 (2500 cycles)	[21]
Orange peel	600	0.1	292.3 (100 cycles)	1	205.1 (1000 cycles)	This work

Table S4 Electrochemical impedance parameters of OPC and OPBNP electrodes

Sample	Impedance（Ω）	
	Rs	Rct
OPC	4.1	291.8
OPBNP	3.2	72.4

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