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Full Length Article

Biomass-derived nitrogen/oxygen co-doped hierarchical porous carbon with a large specific surface area for ultrafast and long-life sodium-ion batteries

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ABSTRACT

Biomass derived porous carbons are economic and attractive materials for anode electrodes in sodium-ion batteries. In this work, a novel porous carbon has been prepared through activation of longan shell, which demonstrates an interconnected hierarchical porosity comprised of macro-, meso- and micro-pores as well with a high specific surface area of 2990 $m^2 g^{-1}$. Benefiting from the unique pore structure and oxygen and nitrogen dual doping, a well-developed ionic and electronic conductivity is achieved. Remarkably, it exhibits an excellent cycling stability with a capacity up to 345.9 mAh g^{-1} at a current density of 0.1 A g^{-1}, and maintains a capacity of 304.2 mAh g^{-1} even at a high current density of 5 A g^{-1} after 1000 cycles as anodes for sodium-ion batteries. These results indicate that the fabricated porous carbon could be a promising electrode material for sodium-ion batteries. The mechanism of such high sodium-ion storage was also discussed with the scan-rate-dependent CV curves to quantify the pseudo-capacitive contribution.

1. Introduction

Sodium-ion batteries have the characteristics of rich sodium resources and low cost, which have attracted the attention of researchers and are considered to be one of the best candidates for possible replacement of lithium-ion batteries in large-scale energy storage [1–3]. In recent years, the study of sodium-ion batteries has made significant progress and the research system has been continuously enriched. Compared with the current mainstream lithium-ion batteries, sodium-ion batteries are relatively low cost, so they are expected to gain more important applications in large-scale energy storage systems in the future [5–8]. However, the practical application is still limited by the lack of suitable positive and negative electrode materials, especially the negative electrode materials with excellent performance and practical application. Sodium and lithium ion batteries have a similar working principle, but the storage behavior of sodium-ions and lithium ions in carbon anode materials is quite different. The commonly used carbon materials such as hard carbon [9], carbon black [10], carbon nanowires [11] and carbon nanoballs [12] show poor cycle performance and low specific capacity when used in sodium-ion batteries. Research shows that regulating the size and structure of pores is one of the effective ways to increase the capacity of carbon materials in sodium-ion batteries [13]. In addition, the degree of graphitization of the carbon material has the effect of its electrical conductivity [14–18]. Besides, structural defects and disorder degree of carbon materials also affect the insertion and extraction of sodium-ions [19–21]. High degree of graphitization, suitable carbon pore structure, is one of the ideal choices for negative electrode materials for sodium-ion batteries [22–25] (see Table 1).

In this study, we applied a simple and efficient route to obtain porous carbon materials by using longan shell as precursor. Longan shell is a type of agricultural wastes and abundantly distributes in the world wide. However, it is generally burnt or rotted naturally, which not only wastes resources but also leads to environment pollution. The high content of hemicellulose and cellulose makes longan shell an appropriate carbon source to prepare carbon materials. Here, we used longan shell as the carbon precursor, and then studied its electrochemical properties for sodium-ion batteries. The longan shell-derived

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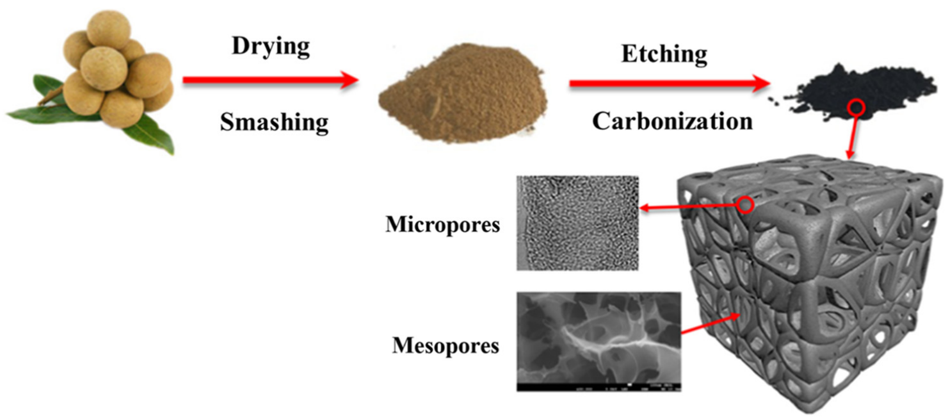
Table 1
Elemental analysis and contents of the N functionalities for the carbons.

Samples	S_{BET} ($m^2\,g^{-1}$)	V_t ($cm^3\,g^{-1}$)	V_{micro} ($cm^3\,g^{-1}$)	Elemental analysis (wt%)			XPS analysis (wt%)		
				C	N	N/C	C	O	N
LPC-600	2433.6	0.658	0.910	40.00	0.36	0.009	92.49	6.65	0.87
LPC-700	2520.1	0.733	1.041	70.41	1.22	0.017	92.76	6.04	1.2
LPC-800	2989.9	0.237	1.167	64.28	1.26	0.019	92.38	6.27	1.36
LPC-850	1927.4	0.579	0.597	60.31	1.17	0.019	92.26	6.75	0.98



Scheme 1. The synthesis of porous carbons from longan shells.

porous carbon possesses a highly-developed micro- and meso-pores and an ultrahigh specific surface area of about 2990.0 $m^2\,g^{-1}$. When used as the anode material for sodium-ion batteries, it exhibits a capacity 350.6 $mAh\,g^{-1}$ at a current density of 0.1 $A\,g^{-1}$. Even at high current density of 5 $A\,g^{-1}$, it maintains capacity of 304.2 $mAh\,g^{-1}$ after 1000 cycles. For the best of our knowledge, such high sodium-ion storage at 5 $A\,g^{-1}$ has never been reported before for carbon materials (see Scheme 1).

2. Experiment section

2.1. Synthesis of porous carbons

The recycled longan shell was soaked in deionized water to wash away impurities, and then dried for 24 h at 130 °C, followed grinded into powder. The as-obtained powder was mixed with KOH solution under stirring at a mass ratio of 1:3. After thoroughly dried at 130 °C in

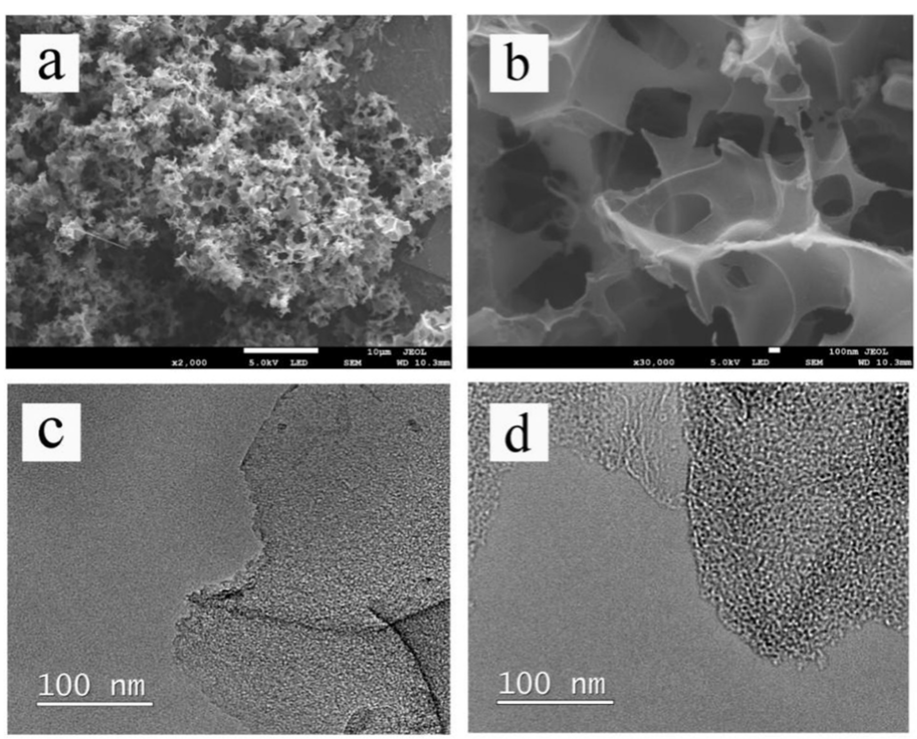


Fig. 1. SEM images (a), (b) and TEM images (c), (d) of LPC-800.