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Low-cost, green synthesis of highly porous carbons derived from lotus root shell as superior performance electrode materials in supercapacitor

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ABSTRACT

Facile production of high quality activated carbons from biomass materials has greatly triggered much attention presently. In this paper, a series of interconnected porous carbon materials from lotus root shells biomass are prepared via simple pyrolysis and followed by a KOH activation process. The prepared carbons exhibit high specific surface areas of up to 2961 m^2/g and large pore volume ~1.47 cm^3/g. In addition, the resultant porous carbons served as electrode materials in supercapacitor exhibit high specific capacitance and outstanding recycling stability and high energy density. In particular, their specific capacitance retention was almost 100% after 10500 cycles at a current density of 2 A/g. Remarkabely, the impact of the tailored specific surface areas of various carbon samples on their capacitive performances is systematically investigated. Generally, it was believed that the highly-developed porosity features (including surface areas and pore volume and pore size-distributions), together with the good conductivity of activated carbon species, play a key role in effectively improving the storage energy performances of the porous carbon electrode materials in supercapacitor.

1. Introduction

Electrical double layer capacitors (EDLCs) are one of the promising electrochemical energy storage devices with high power characteristics [1–3], which have been proved to be useful in consumer electronics, memory backup systems, uninterruptable power sources, and hybrid electric vehicles [4,5]. EDLCs with nanostructured activated carbon (AC) electrode materials from natural products have attracted considerable attention due to their scalability, low-cost, excellent cycle stability, and attractive overall performances [5–8]. As a result, much effort has been devoted to increase the specific capacitance and energy density of carbon-based EDLCs that make them more capable for the primary power sources [9–16].

Generally, the energy storage performance of EDLCs is associated with the adsorption of electrolyte ions on large specific surface area (SSA) of carbon based electrodes. As we know that, high specific surface areas and accessible pores adapted to electrolyte ions are highly desired for EDLCs [17–24]. As a result, various synthetic methods have been attempted to enhance the SSA and pore volume of the carbon materials. For example, literatures reported that utilizing specific template techniques can prepare highly porous carbons [25–27], which exhibited excellent specific capacitances and rate capability. Another promising way to produce porous carbon materials with tailoring pore structure is the carbide-derived carbon (CDC) technique [28], but, their surface areas and pore volumes of the resultant CDCs are lower than those of zeolite-templated carbons. In addition, selective etching of metals from metal carbides and the formation of carbide-derived carbons (CDC) only offer very narrow pore structure [29,30]; furthermore, they always suffer from limited SSA of micropores and tortuous pore shape, which would greatly limit their potential applications [31].

Recently, hydrothermal carbonization (HTC) was considered as one of well-developed industrial techniques to produce porous carbon from natural products due to its large-scale synthesis, low-cost, low-temperature, and environmentally-friendly advantages [32–36]. To date, various natural products (c.a. fungi, corn grain, lignocellulosic materials, sunflower stem, hair, and starch) derived porous carbons have been prepared via HTC treatment process [37–43]. Results discovered that the carbon products yield is high, and the resultant carbons display tailoring porosity and show great potential as electrode materials in EDLCs. Unfortunately, the serious disadvantages of carbons originated from natural biomasses

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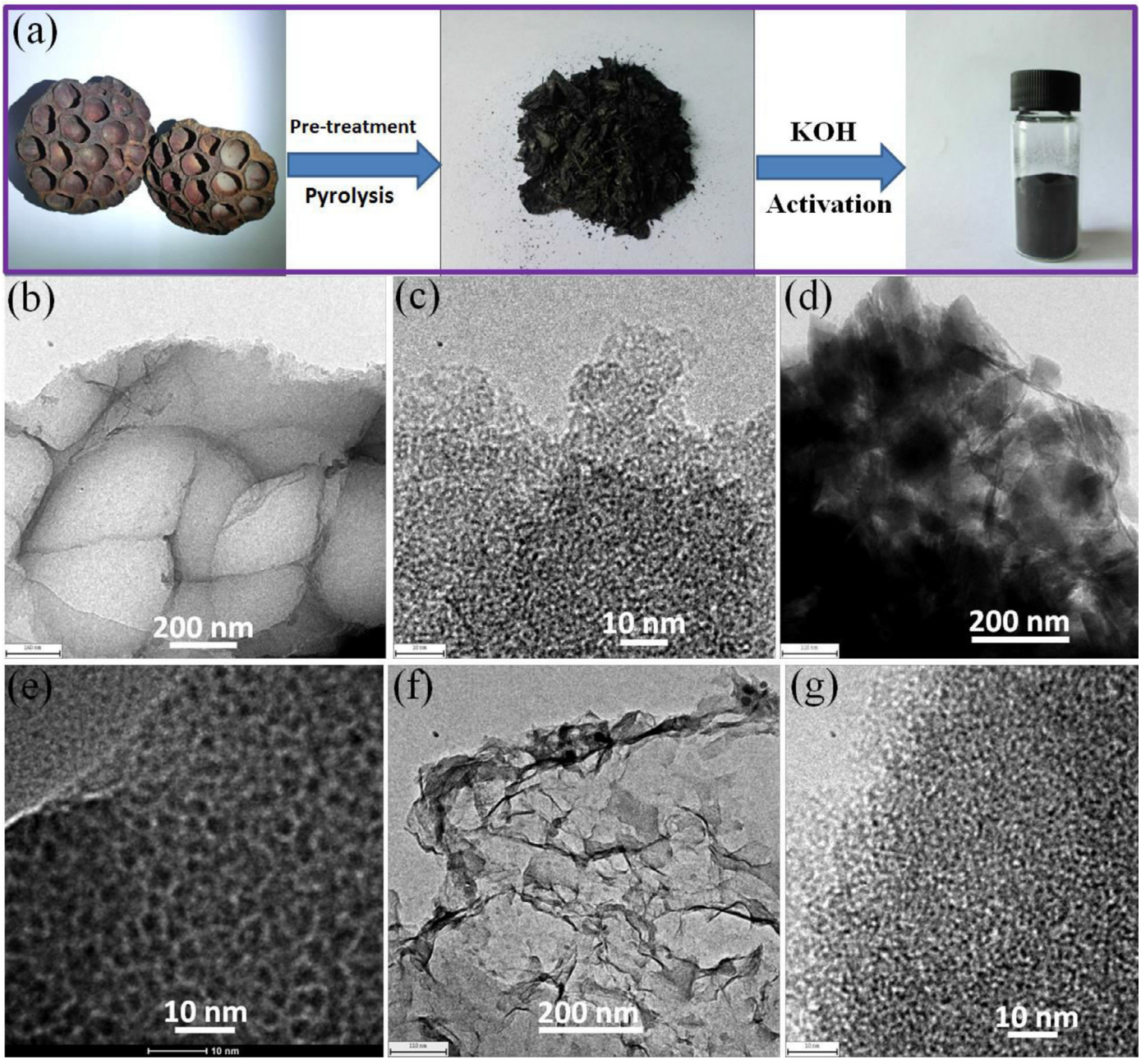

Fig. 1. (a) The preparation process of porous activated carbon samples from lotus root shell; (b, c) TEM images of the prepared carbon C-700-4; (d, e) TEM images of the prepared carbon C-800-4; (f, g) TEM images of the prepared carbon C-900-4.

lack sufficient uniformity and consistency in their porous properties, which could be prohibitive for practical applications of EDLCs [44,45].

It should be pointed out that the classical activated carbon synthesis route via pyrolysis of organic species followed by an activation process is likely to be considered as a promising commercial solution [46]. Thus, developing novel methods for the low-cost synthesis of ACs with large pore volume, high SSA and well-controlled microstructure are crucial for satisfy commercial EDLCs applications [47–51]. Wherein, we employ facile pyrolysis followed by a chemical activation process to convert a bio-waste lotus root shell into highly-developed porous carbon materials. As known, there are abundant lotus root shell in China and other countries [52], but only small proportion of lotus seed embedded in louts root are used as the traditional Chinese medicine and food and tea [53], and main proportion product lotus root shell becomes wastes of markets and factories, thereby resulting in great resources waste and environmental pollution. As a consequence, it is of great importance for developing low-cost, facile and scalable synthesis of highly-porous carbons from lotus root shell bio-wastes currently.

In our study, a series of lotus root shell-derived carbon species with different SSA and multiple pore-size-distributions (PSD) can be achieved via simple pyrolysis treatment followed by a KOH activation process, and detailed preparation process can be seen in Fig. 1(a). The prepared carbons display ultra-high specific surface area of 2961 large pore volume of 1.47 cm^3/g, high energy density and excellent recycling durability in EDCLs. More importantly, the specific porous carbon materials with high SSA from biomass would highlight their potential in such as energy storage, catalytic, and environmental engineering fields.