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Walnut shell – Derived activated carbon: Synthesis and its application in the sulfur cathode for lithium–sulfur batteries

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ABSTRACT

Biomass walnut shell was used to prepare activated carbon (AC) through a carbonization treatment and an activation procedure with potassium hydroxide (KOH). AC showed hierarchical pores: 0.6 nm micropores, 2.7 nm mesopores and macropores with average diameter of 50 nm, providing a large specific surface area of 2318 $m^2\ g^{-1}$. This highly porous AC was tested as a host material to encapsulate sulfur via a vapor phase infusion process. The developed AC-S electrode showed a high initial specific capacity of 1350 mAh g^{-1} and good capacity retention over 100 cycles at 0.1 C for lithium–sulfur battery.

1. Introduction

Among various types of rechargeable batteries, lithium-sulfur (Li-S) battery has been considered as one of the most promising energy storage system in broad applications ranging from electric vehicles to large-scale grid energy storage owing to its extremely high theoretical capacity. In addition, sulfur is naturally abundant, low cost and environment friendly. Despite these advantages, the practical applications of Li-S batteries are hampered by several challenges: the dissolution of lithium polysulfide intermediates (Li_2S_x,$4 \le x \le 8$) into electrolytes, the shuttling effect associated with the dissolved polysulfides, the insulating nature of sulfur and its discharged product, and the large volume expansion (up to 80%) of sulfur upon lithiation [1–6].

One of the most efficiency approaches is to encapsulate sulfur with conductive host materials, typically mesoporous carbon, which can improve the conductivity and physically confine polysulfide species within the host during cycling [7–13]. For producing porous carbon with narrow pore size distribution, ordered pore structure and large specific surface area, template-based methods are usually used. In general, the preparation procedure is nanocasting of a carbon precursor with nano templates, followed by a carbonization treatment and finally the removal of templates to leave behind a porous carbon [14,15]. The tedious processing conditions always mean high cost and big environmental impact. Therefore, cheap and eco-friendly biomass has been used to prepare porous carbon and other carbon nanostructure, as a cost effective, facile and simple method [16–19]. Recently, biomass, such as pig bone [20], poplar catkin [21], spirulina [22], soybean hulls [23], and shrimp shell [24], have been explored to prepare porous carbon as host materials for sulfur. Various biomass precursors lead to different morphologies, structures and electrochemical performances. The soybean hulls-derived activated carbon, which has a high specific surface area of 1232 $m^2\ g^{-1}$ but low pore volume of 0.5394 $cm^3\ g^{-1}$, exhibits a relatively fast capacity fading [23]. J. Qu et al. [24] tuned the pore sizes of AC through smartly selective removal of $CaCO_3$ in shrimp shell. But they were hard to improve the total pore volume. The increase of total pore

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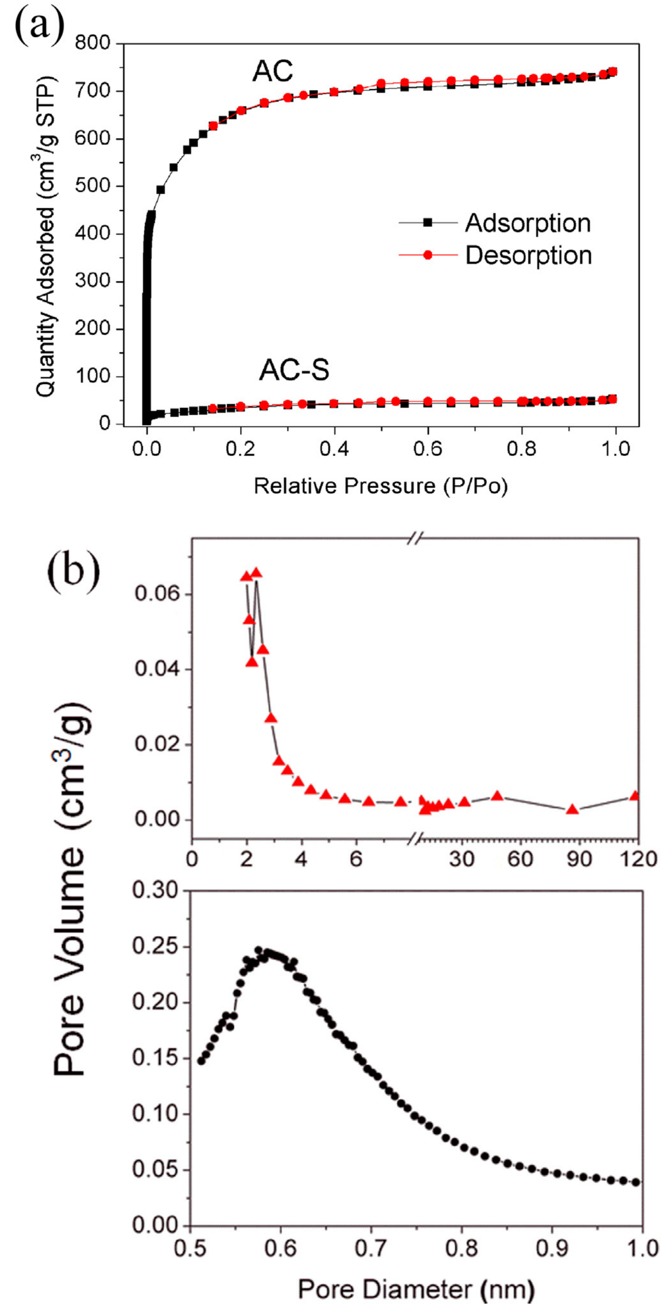

Fig. 2. (a) N_2 adsorption-desorption isotherms and (b) BJH pore distribution of AC.

volume was at the expense of specific surface area. Finally a moderate electrochemical performance was obtained with a total pore volume of 0.853 cm^3 g^{-1}. In these two cases, the synthesized AC materials are limited by the intrinsic structures of their biomass precursors and have low total pore volume. Actually, high pore volume is one of the key factors for the performance of Li-S battery [25,26]. Therefore, it is important to select suitable biomass precursors to prepare AC with both high pore volume and high specific surface area.

In the present work, walnut shell, which has lots of mesopores

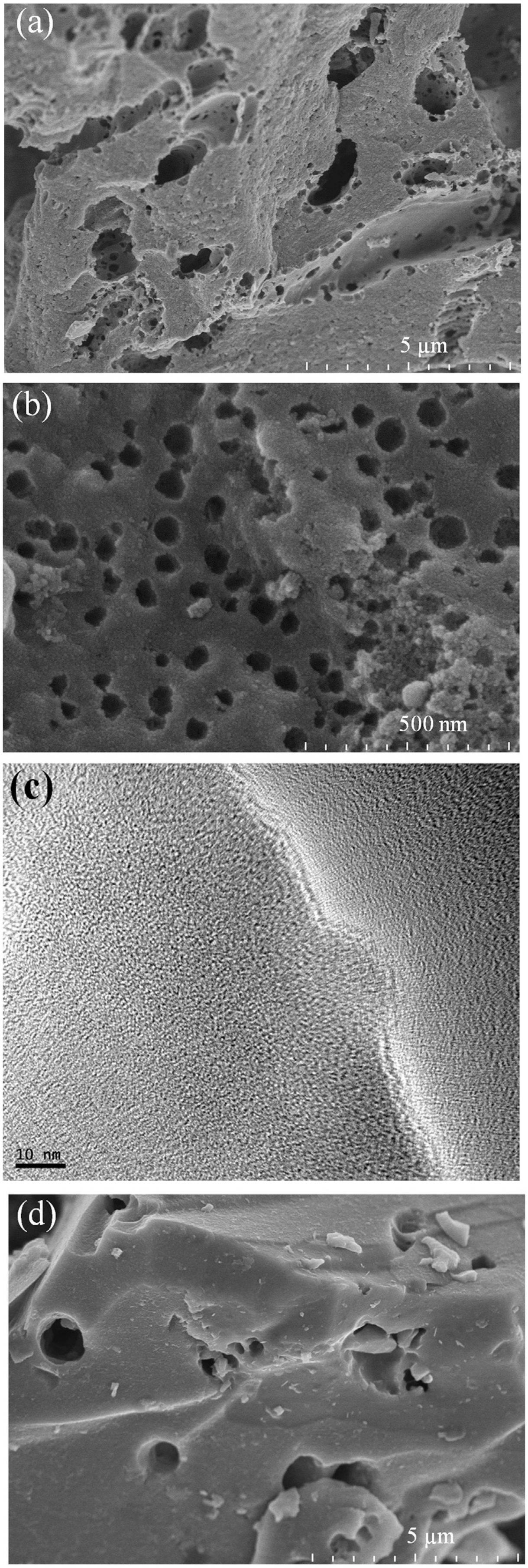

Fig. 1. Typical SEM images of AC with different magnifications: (a) low magnification, (b) high magnification. (c) Transition electron microscopy (TEM) image of AC; (d) SEM image of AC-S.