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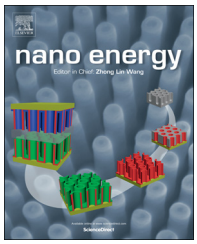

RAPID COMMUNICATION

Porous layer-stacking carbon derived from in-built template in biomass for high volumetric performance supercapacitors

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Abstract
Two-dimensional (2D) porous graphene-based materials such as graphene nanomesh, activated graphene and curved graphene, possess high gravimetric performances due to their high surface area and short ion transport path. However, their poor volumetric performances come from low density and/or high pore volume of the electrode materials, as well as their high manufacturing cost, which would limit their further applications. In this work, densely porous graphene-like carbon (PGC) materials were greenly synthesized through hydrothermal treatment of fungus (*Auricularia*) and subsequent carbonization process. Layer-stacking PGC derived from cell walls of fungus has high surface area (1103 $m^2 g^{-1}$), high bulk density (about 0.96 g cm^{-3}), and hierarchically interconnected porous framework, which can provide with more storage sites and short transport paths for electrolyte ions, and enhance the overall conductivity of the electrode. As a result, the PGC electrode shows ultra-high volumetric capacitance of 360 F cm^{-3} and excellent cycling stability with 99% capacitance retention after 10000 cycles. More importantly, the as-assembled symmetric supercapacitor delivers superior volumetric energy density of 21 Wh L^{-1} and excellent cycling stability (96% specific capacitance retention after 10000 cycles). These exciting results suggest a low-cost and environmentally friendly design of electrode materials for high volumetric-performance supercapacitors.

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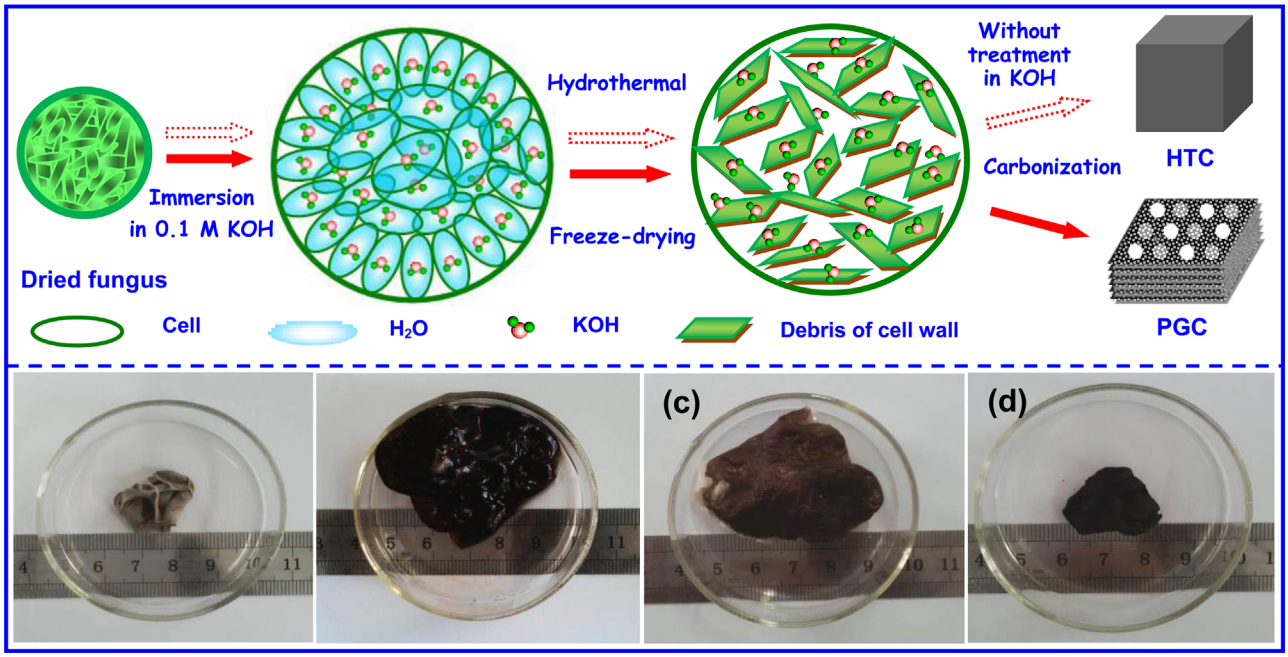

Scheme 1 (Up) Schematic illustration of the formation of hydrothermal treatment carbon (HTC, without treatment in KOH) and compact densely porous graphene-like carbon (PGC) materials. (Down) Photos of fungus (*Auricularia*) and the obtained carbon material: (a) The original dried fungus; (b) Swelled fungus after hydrothermal treatment in 0.1 M KOH solution; (c) Freeze-dried fungus after hydrothermal treatment; (d) The as-obtained carbon materials by carbonization of freeze-dried fungus.

Introduction

With a fast-growing demand for portable electronic devices and hybrid electric vehicles, supercapacitors have attracted more attention due to their high specific power and long cycle life [1-6]. However, their low energy density, especially for volumetric energy density, which arises from inferior volumetric capacitance, would limit their practical applications in the future [7,8]. Porous carbon materials, such as activated carbon, carbon nanotubes, graphene and templated carbon, are selected as electrode materials for electrical double layer capacitors (EDLCs), where the capacitance comes from the pure electrostatic charge accumulated at the electrode/electrolyte interface [4,9-14]. Consequently, it is important to further increase their porosity and specific surface area for the enhanced capacitance. However, it is a great challenge for obtaining high volumetric capacitance due to the low density of carbonaceous carbons (typically less than 0.5 g cm^{-3}) [15-17].

Considering the scalable manufacturing and reasonable cost, activated carbons (ACs) are widely used in the commercial devices [18]. The majority of ACs are derived from the carbonization of carbon precursor (*e.g.* wood, coal, coke, nutshell) and subsequent physical and/or chemical activation [19,20]. Traditionally, high microporosity, high specific surface area ($\sim$3000 m^2 g^{-1}) and moderate specific capacitance (200-300 F g^{-1}) of ACs can be obtained through KOH activation [21]. However, this activation process needs high activating agent loading, usually four times the precursor, which is highly corrosive for the industrial equipments during heat treatment. Additionally, the limited power characteristics of ACs mainly originate from poor pore accessibility of the electrolyte ions at high scan rates due to their high microporosity [11,22-24].

Recently, two-dimensional (2D) graphene materials, such as graphene nanomesh, activated graphene and curved graphene, possess high power performances due to their high surface area and short ion transport length in the thin dimension [12,13,25-28]. Unfortunately, the poor volumetric performances due to their low density or high pore volume, and their high manufacturing cost, would limit their further applications [29].

It is worth noting that fungus (*Auricularia*), a kind of eukaryotic organisms, has been widely used in the food industry and medicine application [30,31]. Due to its worldwide abundance, fast growth rate and rich chitin in fungal cell, fungus can act as a promising carbon precursor [32]. Herein, for the first time, we report a novel strategy for green synthesis of three-dimensional (3D), densely porous graphene-like carbon (PGC) through the hydrothermal treatment of fungus in 0.1 M KOH solution and subsequent carbonization process, as shown in Scheme 1. During the hydrothermal process, KOH is introduced into the cell of fungus and acts as in-built template that prevents the adjacent cell walls from fusion/agglomeration during the carbonization. At the same time, KOH can act as activating agent for the construction of porous carbon framework. Consequently, layer-stacking graphene-like carbon derived from cell walls of fungus has high surface area (1103 m^2 g^{-1}), high bulk density (about 0.96 g cm^{-3}), and hierarchically interconnected porous framework. As a result, the as-obtained porous carbon material shows an excellent cycling stability (99% capacitance retention after 10000 cycles) and ultra-high volumetric capacitance of 360 F cm^{-3}. Moreover, the as-fabricated PGC symmetric supercapacitor delivers an excellent cycling stability (96% capacitance retention after 10000 cycles) and high gravimetric and volumetric energy densities of 22 Wh kg^{-1} and 21 Wh L^{-1}, respectively, higher than most previously reported carbon materials in aqueous electrolyte [14,32-42].

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