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3-dimensional interconnected framework of N-doped porous carbon based on sugarcane bagasse for application in supercapacitors and lithium ion batteries

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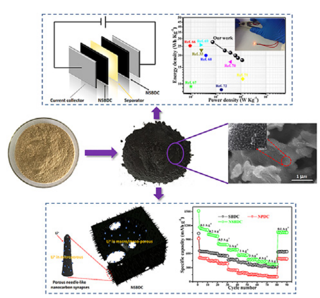
HIGHLIGHTS

- 3D frameworks N-doped porous carbon is produced using sugarcane bagasse as prototype.
- The product displays high specific capacitance (298 F g^{-1}) and superior rate capability.
- The two-electrode asymmetric system shows high energy density (49.4 Wh kg^{-1}).
- The carbon-based symmetric supercapacitors shows high energy density (27.7 Wh kg^{-1}).
- The product also possesses a high reversible capacity (1148 mAh g^{-1}) for LIB.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work, N-doped biomass derived porous carbon (NSBDC) has been prepared utilizing low-cost agricultural waste–sugarcane bagasse as the prototype, and needle-like PANI as the dopant. NSBDC possesses a special 3D interconnected framework structure, superior hierarchical pores and suitable heteroatom doping level, which benefits a large number of applications on ion storage and high-rate ion transfer. Typically, the NSBDC exhibits the high specific capacitance (298 F g^{-1} at 1 A g^{-1}) and rate capability (58.7% capacitance retention at 20 A g^{-1}), as well as the high cycle stability (5.5% loss over 5000 cycles) in three-electrode systems. A two-electrode asymmetric system has been fabricated employing NSBDC and the precursor of NSBDC (sugarcane bagasse derived carbon/PANI composite) as the negative and positive electrodes, respectively, and an energy density as high as 49.4 Wh kg^{-1} is verified in this asymmetric system. A NSBDC-based whole symmetric supercapacitors has also been assembled, and it can easily light a 1.5 V bulb due to its high energy density (27.7 Wh kg^{-1}). In addition, for expanding the application areas of NSBDC, it is also applied to lithium ion battery, and a high reversible capacity of 1148 mAh g^{-1} at 0.1 A g^{-1} is confirmed. Even at 5 A g^{-1}, NSBDC can still deliver a high reversible capacity of 357 mAh g^{-1} after 200 cycles, indicating its superior lithium storage capability.

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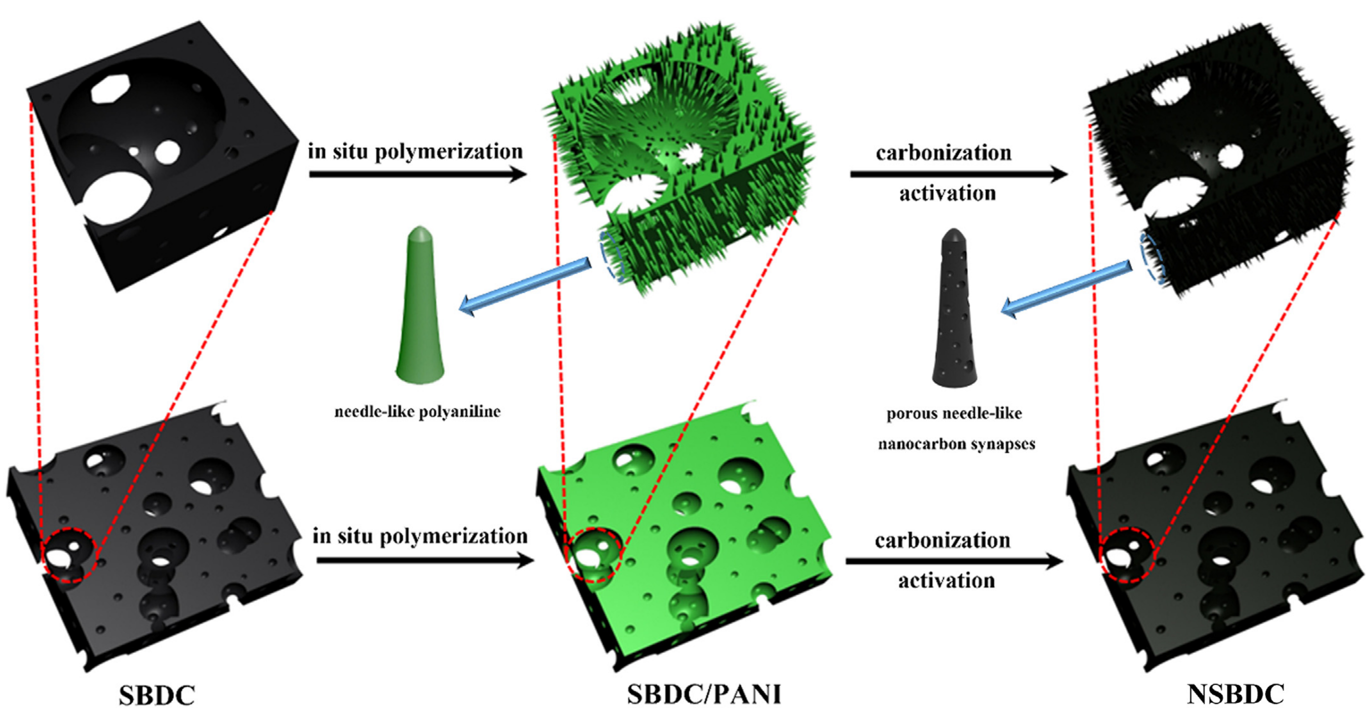
1. Introduction

Facing the increasingly serious energy and environmental crisis, electrochemical energy storage devices (EESD, such as supercapacitors (SC) [1], lithium ion batteries (LIB) [2], and lithium-sulfur batteries [3]) have attracted the attention of researchers due to they can efficient and clean use of energy [4]. Among these materials, carbon materials exhibit high specific surface area, good chemical stability, high electronic conductivity, long cycling life and adjustable surface functional groups [5]. Hence, carbon materials are considered to be superior electrode materials for EESD [6]. At present, many kinds of carbon materials, such as graphene [7], carbon nanotube [8], carbon nanofiber [9], have been used for EESD. However, the preparation process of the above carbon materials are complex [10,11]. Moreover, in order to meet the electrochemical performance requirements of EESD, they need further processing (such as nitrogen doping treatment [12] and activation treatment [13]), and these preparation processes limit their widespread application to EESD. Therefore, the development of new types of carbon materials with excellent electrochemical performance and simple preparation method has become a key element in EESD research.

Biomass materials have evolved over millions of years in nature and possess the multi-dimensional, polymorphic and renewable characteristics. Crop waste is the most common biomass material, and many countries have harvested a large amount of them every year by agricultural production. However, most of crop waste is treated by burning directly into air especially in developing country. This approach not only causes waste of biomass energy, but also causes great pollution to the environment [14]. Actually, the main ingredients of crop waste are cellulose, hemicellulose and lignin [15], which are excellent carbon sources. Therefore, in recent years, researchers are committed to converting crop waste into carbon materials, and various crop wastes resources such as rice straws, corncobs, kenaf stems, and peanut skins have been reported as the precursor to preparation carbon materials [16–19].

In particular, some crop waste derived carbons (CWDC) are very suitable as the electrode material of EESD due to their advantages of multi-dimension and polymorphism, which has been confirmed by many successful researches. For instance, Zhang et al. reported porous carbon prepared from lotus pollen, and this kind of CWDC exhibited the excellent electrochemical performance (applied to SC), which is attributed to the fact that the lotus pollen has a lot of mesoporous structures [20]; Niu et al. also showed that cattle bones derived carbon possessed the excellent electrochemical performance (applied to LIB), which is due to the self-activation induced by hydroxyapatites within the cattle bone [21]. In addition, incorporation of heteroatoms into carbon materials could decrease charge transfer resistance and improve wettability, and thereby further improve the electrochemical performance of carbon materials [22,23]. This method was also applied to bio-carbon and had made some progress, e.g., the specific capacitance of willow catkin derived bio-carbon increased from 249 to 298 $F g^{-1}$ when bio-carbon was doped with N and S atoms [24].

Sugarcane bagasse (SB), is the solid residue derived from sugarcane after extracting cane juice, and like the other agricultural wastes, it is a carbon rich biomass, suitable for bio-carbon production [25]. In our previous study, we prepared the bio-carbon with 3D interconnected frameworks and abundant surface oxygenated functional groups by one-step pyrolysis and activation synthesis method when SB as the carbon sources [26]. We have found that the 3D interconnected frameworks structure (3DIFS) is favorable for ion diffusion, and the surface oxygenated functional groups is suitable for preparation of bio-carbon based composites. Herein, we are committed to developing N-doped SB derived bio-carbon with polyaniline as the dopant. First, SB derived bio-carbon (SBDC) was obtained based on previous work; then, SBDC was covered by needle-like polyaniline (SBDC/PANI composite) via in-situ polymerization method; finally, nitrogen-doped SBDC (NSBDC) was prepared by step-by-step carbonization and activation method (as shown in Scheme 1). For NSBDC, it possesses a 3DIFS attributed to the SBDC framework, and also the suitable nitrogen content and high specific surface area due to the carbonized-activated cladding needle-like PANI. Thence, NSBDC shows excellent rate capability and superior cycling stability as electrode materials for SC and LIB. This work may provide a new research idea and method for common crop waste applied to EESD.



Scheme 1. Schematic illustrations of the preparation process of NSBDC.