

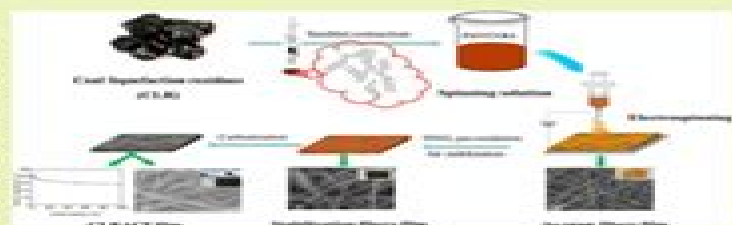
Coal Liquefaction Residues Based Carbon Nanofibers Film Prepared by Electrospinning: An Effective Approach to Coal Waste Management

Xiao Li,^{1,2} Xiaodong Tian,¹ Tao Yang,^{1,2} Yiting He,^{1,2} Wenhong Liu,² Yan Song,^{1,2} and Zhanjun Liu¹¹CAS Key Laboratory of Carbon Materials, Institute of Coal Chemistry, Chinese Academy of Sciences, Taoyuan South Road, 030001 Taiyuan, China²Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049, China

Supporting Information

ABSTRACT: As a major byproduct of direct coal liquefaction, coal liquefaction residue (CLR) waste is environmentally harmful but also valuable. Considering environmental and economic efficiency, exploiting these wastes as electrodes for new generation energy storage devices will increase the economic value and decrease environmental pollution synchronously. In this regard, CLR is used to prepare carbon nanofibers film for supercapacitors via electrospinning followed by HNO₃ preoxidation, air stabilization, and carbonization processes for the first time. The influences of HNO₃ preoxidation over the formation of fiber morphology, textural structure, surface chemistry, and electrochemical performance are investigated. Our work demonstrates that HNO₃ preoxidation can enhance the content of the heteroatom of the as-spun nanofibers and promote the polymerization of the asphaltene (CLRA) molecular during air stabilization, leading to the changes of the thermal behaviors and thus avoiding the fibers melting successfully. The results show that the obtained sample exhibits a 3D nonwoven network with an average diameter of 200 nm, good flexibility, high content of nitrogen, and large specific surface area. Owing to these merits, the as-obtained sample shows high specific capacitance, excellent rate capability (143 F g⁻¹ at 100 A g⁻¹), and long lifespan (98% of its initial capacitance after 10 000 cycles) as supercapacitor electrode.

KEYWORDS: Coal liquefaction residues, Asphaltene, Carbon nanofibers film, Supercapacitors, Electrospinning, HNO₃ preoxidation



INTRODUCTION

Energy storage devices play an essential role in tackling the issues of storage of the intermittent energy from solar or wind and alleviating environment and energy crises.^{1–3} Among modern energy storage technologies, supercapacitors (SCs) have become a fast-growing system due to the distinct characteristics of high power density, safety and long cycling life.^{4–6} The United States and European Union have reported that carbon materials play an important role in energy devices. However, large amounts of carbon-based electrodes made by conventional slurry-coating method can hardly fulfill the demands of the fabrication of high-performance SCs because the polymer binder not only decreases the conductivity of the active materials but also blocks the contact between active material and electrolyte, which leads to low utilization efficiency and undesirable rate capability.⁷ Therefore, the preparation of high-quality integrated electrode is of great significance. Moreover, this innovative device also provides a new approach to develop highly flexible and lightweight SCs

used as power supply for next-generation portable and wearable electronic applications. Owing to its advantages of high surface area, light weight, structural controllability, and convenience in fabrication, electrospinning carbon nanofibers (CNFs) film has drawn great attention as flexible and free-standing electrodes for SCs.^{8,9} To date, a myriad of precursors, such as coal,¹⁰ pitch,¹¹ biomass,¹² lignin,¹³ and so on, has been used to fabricate the CNF films.

As a major byproduct of direct coal liquefaction, coal liquefaction residues (CLR) waste is environmentally harmful but also valuable.^{14,15} It would be meaningful if we can extract valuable organic components to fabricate high-value-integrated free-standing products for electronic and energy-related applications rather than combustion or gasification, which can increase the economic value and decrease environmental

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