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Porous Graphitized Coal Anodes for Sodium-Ion Batteries via Flash Joule Heating and Catalytic Activation

Abdalla Mohamed Ali Mohamed

School of Materials and Energy, University of Electronic Science and Technology of China, Chengdu, 611731, Sichuan, China

Abstract

Recently, the lithium-ion batteries (LIBs) industry has become more expensive due to the limited resources and the uneven global distribution of lithium, with its rising prices. Therefore, sodium-ion batteries (SIBs) are promising as an attractive replacement to LIBs for storing energy because of the abundance of sodium resources. Additionally, demand for natural graphite in the battery industry has increased dramatically despite its limited reserves; this requires finding new materials and methods to provide alternatives for the graphite. Whereas coal is a high quality, widespread carbon source, it consists of graphitic crystalline domains connected with amorphous carbons that the graphitization process can further transform into synthetic graphite. The flash Joule heating (FJH) method is considered a time- and energysaving, strong candidate for a traditional graphitization method. The cost to transform 1 ton of amorphous carbon into graphene using FJH ranges from $30 to $161, depending on the starting source. In contrast, the cost of synthetic graphite is approximately 13 USD/kg, and for natural graphite, it is approximately 8 USD/kg. As an emerging synthetic method, FJH exhibits great superiority in environmental friendliness and low time and energy consumption, making it promising in transforming coals into graphitic carbon materials. Based on these considerations, porous graphitized coal anode materials for SIBs were prepared using a two-step process involving catalytic activation using nickel chloride, iron chloride, and zinc chloride catalysts, followed by high-temperature graphitization using FJH. XRD, Raman spectroscopy, SEM, TEM, and BET analyses confirmed the coal sample (FHC) transformation from an amorphous to a crystalline structure, with expanded interlayer spacing, increased porosity, and reduced defects. These structural features significantly enhance sodium storage capacity and electrical conductivity. The electrode of the FHC sample, prepared via flash joule heating, showed higher initial charge and discharge capacities of 298.9 and 642.7 mAh/g at 0.1 C. The superior specific capacity of FHC can be attributed to its improved crystallinity and enhanced porosity resulting from high-temperature catalytic graphitization.

The FHC electrode demonstrated outstanding cycling stability, with a capacity retention of 99% after 300 cycles at 2C, confirming the effectiveness of this graphitized coal material for high-performance SIB applications.
Therefore, the low price of coal and its abundant reserves, combined with the FJH technology, can be exploited to produce high-quality graphitic coal for use as anode materials for SIBs.

Keywords: Coal; Sodium-ion batteries; Flash Joule heating; Graphitized coal.