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Ultra-long cycle life of flexible Sn anode using DME electrolyte

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ABSTRACT

Sodium-ion batteries (SIBs) are highly anticipated energy storage devices due to the low-cost, widely available resources, and similar electrochemical performances with lithium-ion batteries. Even though excellent performances are demonstrated for SIB cathodes, the SIB anodes still need improvement to meet the commercial standards. Tin (Sn) anode is a popular anode that has high prospects but the previous reports show unsatisfactory electrochemical results. Here we demonstrate the excellent electrochemical performance of a flexible Sn anode for SIBs in DME electrolyte for the first time. The spherical Sn particles are embedded on carbon fibers by the facile electrospinning method. The Sn anode delivered a capacity of 661 mAh g^{-1} at 0.5 C. Also, the Sn anode delivered exceptional cycling performance up to 30,000 cycles with a negligible capacity degradation of 0.002% per cycle at 25 C. Moreover, a full cell with freestanding Sn anode was assembled for the first time by coupling with $Na_3V_2(PO_4)_3$ delivers a maximum energy density of 114 Wh kg^{-1} and a power density of 3256 W kg^{-1} based on the mass of total active materials demonstrating excellent prospects.

1. Introduction

Lithium-ion batteries (LIBs) are considered ideal energy storage devices nowadays due to the superior properties [1]. However, the recent rise in electric vehicles and personal electronics has severely raised the utilization of LIBs, negatively affecting the market as lithium resources are limited. Sodium-ion batteries (SIBs) are potential candidates that can substitute LIBs as Na^+ and Li^+ have comparable electrochemical properties [2–4]. To realize practical applications, the development of suitable cathode and anode materials is crucial. Most of the cathode materials in SIBs are reported to have excellent electrochemical performances [5]. However, the electrochemical performances of anode materials are generally poor and inadequate. For instance, graphite, the popular anode material in LIBs, exhibits inadequate capacity in SIBs [6,7]. Alloying materials are favored as anode materials in SIBs due to high theoretical capacity and low voltage [8,9]. Among alloying materials, tin (Sn) is widely investigated due to its high theoretical capacity (847 mAh g^{-1}), lower plateau potential, and low toxicity [10]. Nevertheless, the volume expansion is a huge concern for Sn anode (~420% upon sodiation to form $Na_{15}Sn_4$) [11]. Most of the previous studies overcome this issue via encapsulation strategies utilizing carbon matrices, nanostructuring, etc. [10].

Encapsulation of active materials in carbon nanofiber is a popular strategy that has multiple advantages. Active materials can directly come in contact with the electrolyte, and the electrons are transported rapidly through highly conductive carbon nanofiber which results in the enhancement of kinetics. Additionally, the CNF will act as a buffer against volume expansion that prevents volume expansion, leading to improved cycling performance. Moreover, it can result in a free-standing and flexible electrode devoid of conducting agents and binders [12–15]. In case of Sn anode, there were several efforts to enhance electrochemical performance by using the free-standing technique. For instance, Chen et al. reported Sn nanodots encapsulated inside carbon nanofibers, which showed cycling performances up to 1300 cycles at 2 A g^{-1} current density in carbonate electrolyte [16]. However, the exploration of the electrochemical performance beyond half-cell is essential for the practical application of the electrode. This is the first report to study about the exploration of full cells based on freestanding Sn anode.

Recently, ether electrolytes are widely studied as it significantly improved electrochemical performance [17]. For example, our group reported the enhanced cycling performance of micron-sized Sn anode up to 5000 cycles by exploiting the DME electrolyte, which possesses a higher ionic conductivity and lower viscosity [18]. The

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