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Flexible, ultralight, and high-energy density electrochemical capacitors using sustainable materials

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ABSTRACT

Development of flexible, ultralight, scalable and non-leaking energy storage devices such as electrochemical capacitors that are on par with commercial standards and offer compliances while retaining safety remain a significant challenge for the realization of wearable devices. Generally, the bottleneck to the improvement of such devices is the need to use ecofriendly electrode and electrolyte materials with desirable surface, electrochemical and mechanical properties. Thus, this study provides a new platform for development of flexible, ultralight, freestanding electrochemical capacitor using a composite of cellulose/SWCNTs (CL/CNTs) electrode films and a new cellulose/$NaHSO_4$ hydrogel electrolyte. Herein, we took advantage of the renewability and flexibility of cellulose in combination with the high conductivity and storage capacity of SWCNTs to create a high specific capacitance, energy and power density. Moreover, the new cellulose/$NaHSO_4$ hydrogel electrolyte provided stable cycling, leading to non-leakage device exhibiting ~100% capacitance retention after 3000 cycles.

1. Introduction

The demand for environmental friendly, low-cost and sustainable energy storage devices [1] is growing very rapidly. The electrochemical energy storage systems such as flexible electrochemical capacitors, synonymously supercapacitors, [2–6] have great potential in providing sustainable livelihood to the global population via low-cost powering of hybrid electric vehicles, and wearable/portable electronic devices [7–9]. The interest of the use of flexible supercapacitors are new emerging energy storage devices is mainly driven by the high power density [10–12] and their ability to bend and twist to conform to the desired robust architecture so as to power back-ups for next-generation flexible electronics [13–15]. However, the main challenges facing the future development of energy storage devices lies on the overall device costs, realization of flexible devices, high energy density, electrochemical stability, and utilization of earth abundant raw materials, reproducible industrial scalability and easily recyclable systems. To provide a solution to most of the above-mentioned setbacks, cellulose-derived materials have gained more attention due to their unique properties such as biodegradability, flexibility, and strong mechanical strength, high thermal and chemical stability [16–18]. Recently, integration of cellulose-derived carbon with graphene, carbon nanofibers (CNFs), reduced graphene oxide (rGO), activated carbon (AC) and carbon nanotubes (CNTs) have been reported to improve electrical conductivity and flexibility for energy storage applications [10,19,20]. For instance, Kang et al [21]. reported specific capacitance, energy and power density of ~50.5 $F \cdot g^{-1}$, 15.5 $mWh \cdot g^{-1}$ and 1.5 $W \cdot g^{-1}$ at 1 $A \cdot g^{-1}$ for flexible device that was fabricated from a composite of bacterial cellulose and CNTs in an ionic liquid based polymer gel electrolyte. Choi et al [22]. showed that cell capacitance of ~100 mF cm^{-2} at 0.2 mA cm^{-2} without impairing of cell capacitance even after 1000 bending cycles can be achieved for a cellulose/AC/CNTs composite based solid-state flexible supercapacitor. Furthermore, layer-by-layer coating of CNTs on cellulose aerogel reported by Hamedi et al [23]., showed super elasticity in wet state, improved compressive strength and good elastic mechano-responsive resistance with excellent specific

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