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Design of a porous gel polymer electrolyte for sodium ion batteries

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ABSTRACT

A separator is essential component for securing the safety and stability of secondary batteries. Sodium ion batteries (SIBs) have been considered as a highly powerful next generation energy storage device, but the conventionally used glass fibre (GF) separators for SIBs do not meet the necessary standards due to their randomly distributed pore structure, which causes severe safety problems and capacity decay. Although many studies have been performed to address these drawbacks, there are still difficulties of controlling the inner pore structure of GF. Herein, a strategy is introduced to control the inner porous nanostructure of GF via non-solvent induced phase separation (NIPS) engineering for the gel-polymer electrolyte in SIBs. We report how different types of porous polymer gel electrolyte inside the GF matrix affect SIB performance in terms of both pore nanostructure and vertical position of polymer layer. As a result of NIPS, the optimized gel-polymer electrolyte in GF facilitates increased ionic conductivity via modified ion transport and displays superior cell characteristics with excellent stability.

1. Introduction

Lithium ion batteries (LIBs), which have been prime energy storage devices until now, have advantages of long cycle life and large potential range for operation [1–3]. In addition, LIBs can facilitate minimizing cell size because of their high energy and power density, and these merits have allowed LIBs to be developed over recent decades and utilized in various fields, such as portable IT devices (laptop, mobile phone, wearable devices, etc.) and x-electric vehicles (EV, HEV, PHEV, etc.) [4,5]. However, the excessive demand for LIBs and limited lithium sources have led to the inflation of the lithium market. Moreover, the research and development of LIBs seems to have reached a zenith, which has triggered many researchers to develop other energy storage devices as substitutes for LIBs, such as Li-O₂ batteries and Li-S batteries [6]. Nonetheless, as these devices also require lithium, the sodium ion battery (SIB) has come to the fore thanks to the great abundance of sodium sources in the earth's crust [7,8]. In addition, SIBs have electrochemical processes nearly identical to those of LIBs, as the chemistry of sodium is similar to that of lithium, both classed as alkali metals in the periodic table. Because of these features, research on SIBs has progressed rapidly to attain a high enough energy density to replace LIBs in application.

SIBs commonly adopt a system composed of an organic liquid electrolyte with a separator between the cathode and anode. Porous

polymer-based separators have been considered as the most adequate separator in LIBs despite their feeble thermal stability, but they are not suited for SIBs owing to their different atomic properties. Hence, glass fibre (GF) is widely used as a separator for SIBs even though the thickness of GF is very far from the standard [9–11]. Moreover, the loosely woven hollow structure of GF and its extremely high porosity may cause thermal runaway and explosion resulting from direct connection between the electrodes, and capacity decay may result from the non-optimized pore size [12,13]. Although these drawbacks of non-optimized porous separators have hindered the development of SIBs, most research on SIBs is still mainly focused on electrode materials [14–16]. To overcome these flaws, there have been few studies regarding alternative separators to replace GF, but they show relatively mediocre cell characteristics due to their low ionic conductivity [17–20]. Thus far, it seems that the modification of GF with electrochemically stable polymers is a typical and simple method for improvement of ion transfer. For instance, the poly(vinylidene fluoride-co-hexafluoropropylene) (PVdF-HFP) copolymer is a representative coating material for GF due to its good thermal and electrochemical stability in the SIB operating voltage window [9,21]. In addition, PVdF-HFP contains fluorine in its principal chain, which could increase its interaction with the liquid electrolyte compared with conventional polyolefin-based separators [10,22]. Furthermore, PVdF-HFP-based membranes retain fine pores after phase separation, which results in

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