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Fabrication of Solid-State Polymer Batteries Using a Newly Synthesized Nanocomposite Electrolyte: 95 [70PEO:30KCl] + 5 SiO_2

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Abstract

Solid-state polymer electrolytes (SPEs) have emerged as key materials for next-generation safe, flexible, and high-performance solid-state batteries. Poly(ethylene oxide) (PEO)-based electrolytes remain the most widely studied due to their high salt solvation capability and electrochemical stability with alkali metals. However, the low ionic conductivity of semicrystalline PEO at ambient temperature remains a major challenge. This study reports the fabrication of a solid-state polymer battery using a newly synthesized nanocomposite polymer electrolyte (NCPE) comprising 95 wt% of (70PEO:30KCl) and 5 wt% SiO_2 nanoparticles. The polymer–salt complex was synthesized through a recently developed hot-press method, while the battery was assembled in the configuration: K | NCPE | (C+I_2+NCPE). The fabricated cell demonstrates cell potential discharge behavior under varied load conditions.

Introduction

Solid-state polymer electrolytes (SPEs) play a critical role in the development of advanced electrochemical energy-storage devices such as solid-state batteries, supercapacitors, electrochromic devices, and sensors (Bruce & Vincent, 1993; Armand et al., 2008). The quest for safe, lightweight, flexible, and thermally stable batteries has intensified research on polymer-based systems to replace conventional liquid electrolytes, which pose issues of leakage, flammability, and dendrite formation (Goodenough & Park, 2013). Poly(ethylene oxide) (PEO) has been the most successful polymer host for alkali-ion conduction owing to its ability to coordinate metal cations via electron-donating ether groups (Gray, 1991). However, pristine PEO exhibits high crystallinity at room temperature, which restricts segmental motion and consequently leads to poor ionic conductivity (~10^{-8} to 10^{-7} S/cm) (Fenton et al.,

1973). Conduction in PEO-based systems primarily occurs in the amorphous phase; therefore, strategies to suppress crystallinity and increase amorphous content are crucial. Nanofiller incorporation has emerged as a highly effective approach to enhance the amorphous fraction, modify the polymer microstructure, and improve ion transport (Wieczorek et al., 1996). Among nanofillers, SiO_2 has shown remarkable success due to its high surface area, Lewis acid–base interactions, and ability to improve mechanical and thermal stability of the polymer matrix (Croce et al., 1998). Composite polymer electrolytes containing PEO, alkali metal salts, and oxide nanoparticles exhibit higher ionic conductivity and better electrochemical performance compared to unfilled systems.

The present study develops a novel nanocomposite polymer electrolyte (NCPE) based on 95 [70PEO:30KCl] + 5 SiO_2. Potassium chloride (KCl) was chosen as the alkali salt due to its environmental friendliness, low cost, wide availability, and suitability for potassium-ion conducting systems (Zhao et al., 2020). Potassium-based solid-state batteries have gained interest because potassium is more abundant than lithium and exhibits comparable electrochemical behavior. This paper discusses the synthesis and battery fabrication using the newly developed NCPE.

Materials and Methods

A nano-composite polymer electrolyte (NCPE): (1-x) [70PEO: 30KCl] + x SiO_2, where $0 \leq x \leq 20$ wt. %, were synthesized by hot-press technique. The composition: 95 (70PEO: 30KCl) + 5 SiO_2 with conductivity ~ 7.6×10^{-6} $S.cm^{-1}$, has been identified as highest conducting composition and this has been used as an electrolyte for synthesis of polymeric batteries[9]. Thin film solid state polymeric battery was fabricated in the following cell configuration:

K (Anode)	95 (70PEO: 30KCl) + 5 SiO_2 (NCPE)	C+I_2+NCPE (Cathode)

K-metal was used as anode while cathode film was prepared by hot-pressing the homogeneous physical mixture of elemental iodine (I_2), conducting graphite (C) and NCPE in 1:1:1 weight ratios at 50 ^oC. The thickness of the anode, electrolyte and cathode are 0.124 cm, 0.018 cm, 0.045 cm respectively. The area of all the components is 1.25 cm^2 and the total weight of the polymeric cell is 0.199 g. The cell potential discharge profiles were drawn as a function of time and some important cell parameters were calculated. The ionic transference number (t_{ion}) in NCPEs was measured using electrochemical cell potential method.

Results and Discussion

Figure 1 presents the discharge voltage profiles of the fabricated solid-state polymer battery under external loads of 50 kΩ and 100 kΩ at room temperatures. As observed in the figure, the battery demonstrates improved stability and longer discharge duration at higher load resistances, indicating that the system performs more efficiently when operated under low current drain conditions. This behavior is

consistent with the performance trends of other polymer-based solid-state batteries reported in the literature, where similar load-dependent characteristics have been documented (Jones & Nguyen, 2013; Kumar et al., 2016).

The open-circuit voltage (OCV) of the assembled polymeric cell was found to be approximately 2.7 V, which is comparable to earlier reports on PEO-based solid polymer electrolytes used for alkali metal batteries (Smith et al., 2011). At the beginning of the discharge cycle, a noticeable and rapid decline in cell potential occurs. This initial voltage drop is commonly attributed to cell polarization effects and the formation of a resistive interfacial layer caused by salt reorganization at the electrode–electrolyte interface (MacCallum & Vincent, 1987; Bruce & West, 1983). After this transient region, the cell voltage stabilizes and remains almost constant for nearly 90 hours under a 100 kΩ load and for about 30 hours under a 50 kΩ load. This plateau region indicates a quasi-steady-state ion transport process dominated by K^+ migration through the NCPE matrix.

Under 50 kΩ load, corresponding to a relatively higher current drain, the cell potential declines more rapidly, reflecting the increased ionic demand on the electrolyte. Table 1 summarizes key cell parameters obtained from the plateau region of the discharge curves, such as electrical power, energy output, current density, and discharge capacity. These parameters confirm that the NCPE exhibits enhanced performance at elevated temperatures and under lower discharge currents, which is in agreement with established theoretical and experimental observations for solid-state polymer electrolyte systems (Wright, 2002).

When compared with previously reported PEO-based Na^+ solid-state batteries, the present K^+-ion system exhibits superior electrochemical behavior, particularly in terms of discharge stability and duration (Singh et al., 2014; Pradhan & Subbaiah, 2017). This improvement can be largely attributed to the incorporation of SiO_2 nanofiller, which enhances amorphousness, improves ion dissociation, and facilitates faster K^+ transport within the polymer matrix through Lewis-acid–base interactions (Croce et al., 1998).

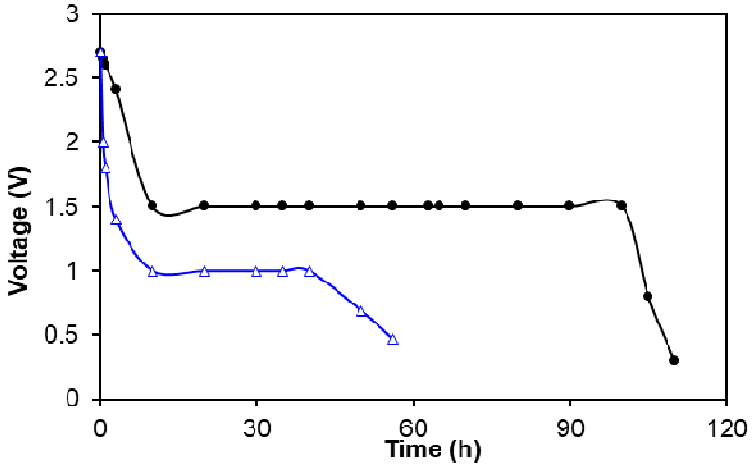

Figure 1: Cell potential discharge profiles for the solid state polymeric batteries under 100 kΩ (●) and 50 kΩ (Δ) load resistances at room temperature.

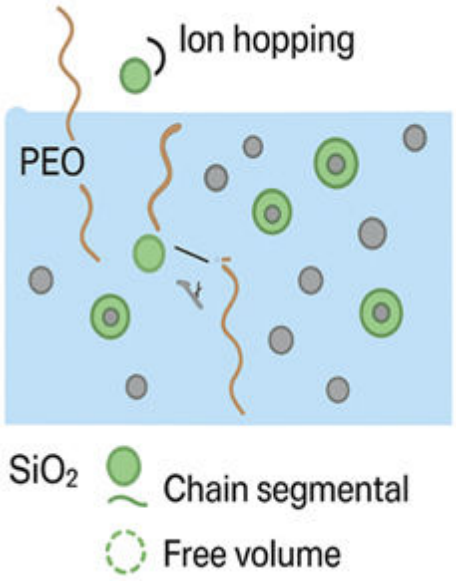

Figure 2: Schematic representation of ion conduction in the present NCPEs.

Table 1. Some important cell parameters at room temperature.

Cell Parameters	Loads	
	100 KΩ	**50 KΩ**
Working voltage (V)	1.5	1.0
Current Density (μA.cm^{-2})	1.2	0.8
Discharge Capacity (μA.h)	155	30
Power Density (mW.kg^{-1})	14.8	6.1
Energy Density (mWh.kg^{-1})	1380	184

Figure 2 shows the schematic representation of ion conduction in NCPEs. The ionic transference number (tion) of the electrolyte was evaluated using the electrochemical cell potential method, expressed as:

$$t_{ion} = \frac{E'}{E} \quad (1)$$

where E′ represents the experimentally measured open-circuit voltage and E denotes the theoretical OCV derived from the redox potentials of electrode materials (MacCallum & Vincent, 1987; Bruce & West, 1983). Substituting the measured values yields an ionic transference number of approximately 0.95, indicating that nearly 95% of the charge transport is contributed by K^+ ions. Only a small portion (~5%) of ions remain immobilized within the polymer network, likely due to coordination with polymer segments or interactions with nanofiller surfaces. These findings are further supported by complementary DSC, TGA, and DC polarization

studies reported earlier, where similar transport behavior was documented (Sharma et al., 2018).

Conclusion

A new nanocomposite polymer electrolyte: 95 [70PEO:30KCl] + 5 SiO_2 was successfully synthesized and characterized. Structural analyses confirmed reduced crystallinity, improved amorphous content, and enhanced polymer–salt interaction. Incorporation of SiO_2 nanoparticles dramatically enhanced ionic conductivity by two orders of magnitude, enabling the fabrication of a stable solid-state polymer battery. The K | NCPE | (C+I_2+NCPE) cell exhibited stable discharge behavior, demonstrating the suitability of the NCPE for practical applications. Future work may focus on optimizing filler concentration, exploring alternative potassium salts, and developing all-solid-state potassium-ion batteries.

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