Gel Polymer Electrolyte for Flexible Lithium-ion Batteries for Wearable Applications

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Lithium-ion batteries (LIBs) are extensively used in portable electronic devices due to their high energy density and theoretical specific capacity. However, conventional LIBs employing liquid electrolytes pose safety risks – particularly leakage and flammability – limiting their suitability for wearable and flexible devices. Gel polymer electrolytes (GPEs) offer a promising alternative, providing enhanced electrochemical stability and safety. By blending acrylate monomers with diverse side chains and carefully tuning their stoichiometry, we tailor the polymer microstructure to enhance Li^+ mobility and mechanical elasticity.

While efforts focused on improving ionic conductivity of GPEs, achieving sufficient flexibility remains a challenge, especially for stretchable or wearable energy storage systems. In this study, we present a UV-curable GPE system that achieves both high conductivity and mechanical compliance. By blending acrylate monomers with diverse side chains and carefully tuning their stoichiometry, we tailor the polymer microstructure to enhance Li^+ mobility and mechanical elasticity. The GPEs were synthesized via UV curing of acrylate monomer blends mixed with $LiPF_6$ or LiTFSI. Key parameters, such as the Li^+: monomer ratio, curing time, and UV exposure distance, were systematically optimized. FTIR spectroscopy confirmed successful polymerization.

As shown in Figure 1, the FTIR spectrum of the monomer mixture exhibits peaks at 1620 cm^{-1} and 1635 cm^{-1}, corresponding to the stretching vibrations of the C=C bonds. After exposure to UV light these peaks disappeared, indicating successful photopolymerization and complete monomer consumption.

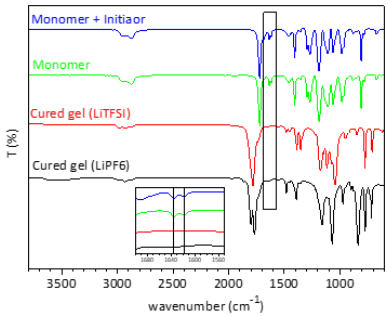

Figure 1. FTIR spectra of monomers and cured gels.

To measure compression strain of cured gels, specimens were prepared in a cylindrical shape with a diameter of 20 mm and a height of 5 mm, and tested in compression using a TA.XT Texture Analyzer at a rate of 0.02 mm/min. Figure 2a represents the compressive stress curves of two types of GPEs. Gel 2 exhibits excellent mechanical performance up to 0.27 MPa compressive stress at maximum load, which is almost 10 times higher than 0.028 MPa of Gel 1, with up to 30% strain at maximum load.

The ionic conductivity of GPEs was tested using electrochemical impedance spectroscopy (EIS) using a blocking symmetric steel//GPE//steel cell from 1 MHz to 100 mHz with an amplitude of 5 mV. In the EIS, the Z_0 intercept of the straight line on the real axis is related to the bulk resistance of GPEs. It can be seen from the inset of Figure 2b that Gel 2 exhibits much lower bulk resistance compared to Gel 1, meaning that its ionic conductivity is higher. Ionic conductivity was calculated by the following formula:
$\sigma = d / R_b \cdot S$, where d, S, and R_b are the thickness, area, and bulk resistance, respectively. The results of Gel 2 revealed that it has an impressive ionic conductivity of 4 $mS \cdot cm^{-1}$.

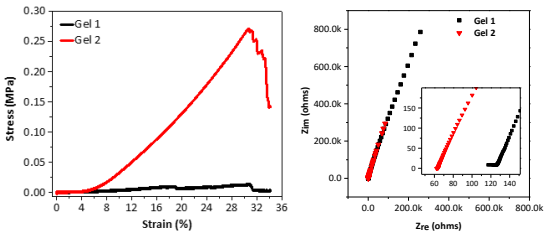

Figure 2. (a) Compression stress-strain curves, and (b) Nyquist plots for cured gels.

This work demonstrates a fast, scalable, and cost-effective approach to fabricating UV-curable GPEs with the dual advantage of high ionic conductivity and mechanical flexibility, paving the way for safer and more adaptable lithium-ion batteries in flexible electronics.

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