Design And Analysis Of Solid-State Battery Using A Unified Electrical Equivalent Circuit Model

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Abstract

Abstract: In the field of energy storage technology, solid-state batteries (SSBs) have come of age, significantly driving the electric vehicle (EV) sector forward and making substantial contributions to sustainability objectives. Compared to Li-ion batteries, SSBs offer numerous benefits, including high energy density, improved safety, longer range, and minimal degradation. This paper presents the parameterization and degradation behavior of SSBs using an electrical equivalent circuit. We tested the coin cell SSB using the Gamry unit, and Nyquist plots are shown for various cycles at different temperatures. Battery parameters are derived from Electrochemical Impedance Spectroscopy (EIS) data to model the SSB. Curve fitting is applied to this data to estimate the battery parameters and form the SSB EEC model. MATLAB is used to model the SSB at the cell level, and to comprehensively assess SSB performance in terms of degradation and thermal modeling, COMSOL software is being utilized.

Introduction:

Solid-state batteries (SSBs) are revolutionizing battery technology and the energy industry, offering safety, reliability, and a longer lifespan. They explore innovative approaches and pave the way for a more sustainable and cleaner energy future [1]. With the potential to transform markets and consumer experiences from portable electronics devices to renewable energy integration, SSBs are a breakthrough technology for the next generation of electric vehicles, shaping the future of sustainable mobility. Fig. 1 illustrates the basic difference between the conventional Li-ion battery and SSB.

Next to the sustainability context, battery innovation plays a vital role in advancing the electric transportation sector, which could significantly contribute to the NetZero target [2]. The fast evolution of this technology is imperative to meet the growing demands for efficient and sustainable energy solutions. In light of this, solid-state battery (SSB) technology has emerged as cutting-edge development, which can tackle key challenges such as safety, high power and energy density, and sustainability [3]. This development can be a promising solution for the future of the EV industry. On the other hand, in EV applications, optimal battery operation concerning safety and efficiency is critical [4]. With this concern, accurately predicting the battery's degradation is critical but challenging due to complex physical characteristics [5]. Degradation is caused by various factors, including temperature variations, charging and discharging rates, number of cycles, internal resistance, depth of discharge, and electrode materials. It is crucial to study these factors to develop techniques that minimize battery degradation and maximize battery life [6].

To build an electrical equivalent circuit of SSB, the parameters are important, as this research is new. We have tested the coin cell SSB using Gamry, and using the EIS data, the Nyquist plot is depicted in Fig. 2. The EIS has been run at different temperatures, such as room temperature and 50°C at different cycles, as shown in Figs. 2 (a) and 2 (b), respectively. Further, we have simulated the SSB in MATLAB environment, and an extended study is going on for the thermal and degradation analysis using COMSOL.

Conclusion:
The present work demonstrates the parameterization and formation of a solid-state battery (SSB) equivalent circuit. As noted, SSB technology is a promising solution for the EV industry, which needs to be sustainable and secure. The SSB uses solid electrolytes, which offer high energy density, better thermal stability, and less degradation. This study shows the SSB's electrical and thermal performance and degradation characteristics using the MATLAB and COMSOL environment.

Reference

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Figures used in the abstract

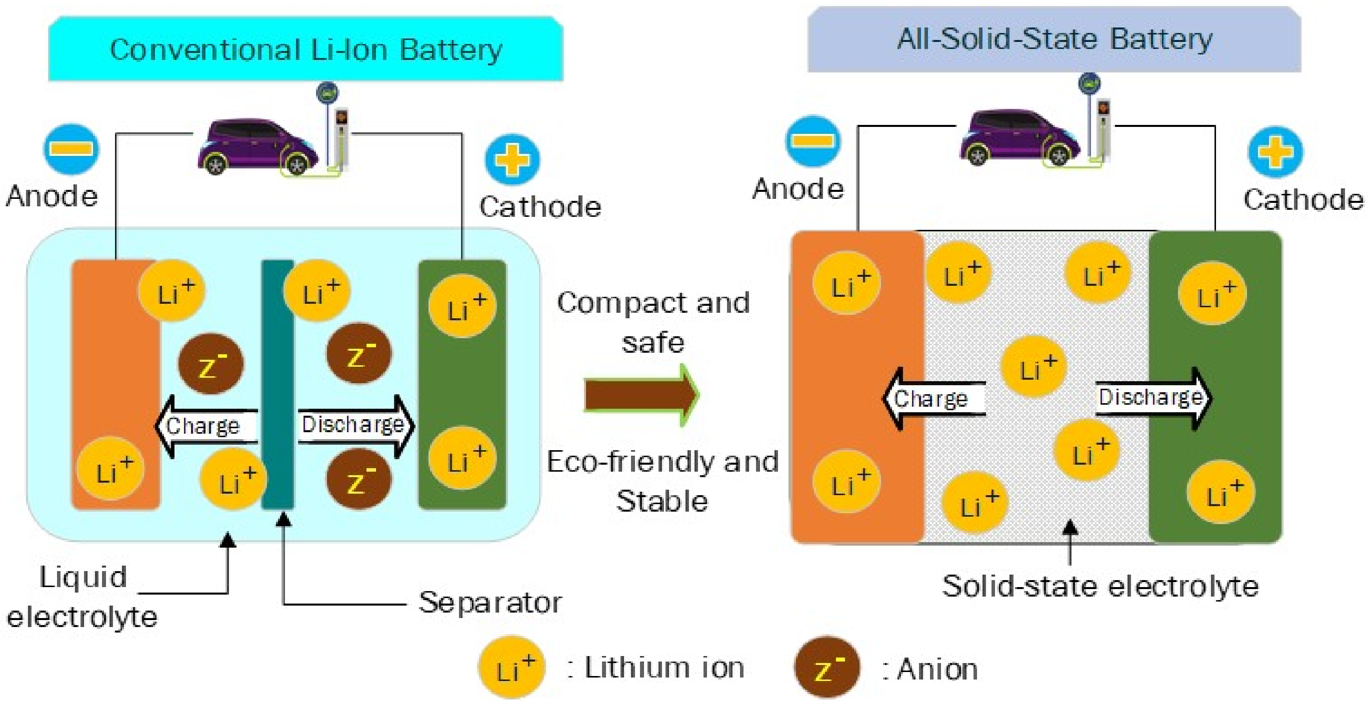

Figure 1

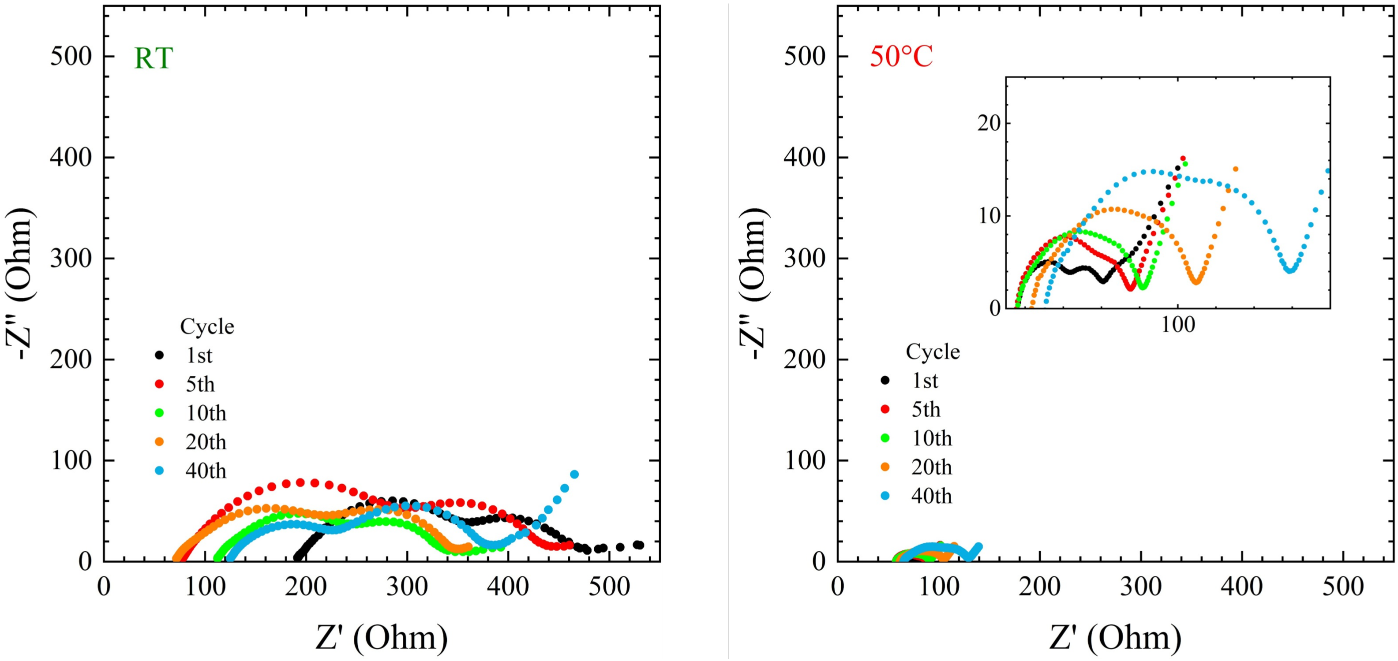
RT
50°C
Cycle
1st
5th
10th
20th
40th
-Z'' (Ohm)
Z' (Ohm)
0
100
200
300
400
500
20
10
0
100

Figure 2