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DETERMINATION OF IONIC CONDUCTIVITY OF POLYMER ELECTROLYTES IN LI-ION BATTERIES USING ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

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ABSTRACT

In this work, we studied the graph of impedance spectroscopy of a solid polymer electrolyte at room temperature for lithium-ion batteries and its temperature dependence. When studying solid polymer electrolytes, Nyquist coordinates and electrochemical impedance spectroscopy were used. The ionic conductivity of the electrolyte was $6.39 \cdot 10^{-6} \frac{1}{Ом \cdot см}$ *at 303 K and* $1{,}07 \cdot 10^{-4} \frac{1}{Ом \cdot см}$ *at 373 K. Maximum conductivity electrolyte based on* $LiTf_2$*was* $3{,}075 \cdot 10^{-5} \frac{1}{Ом \cdot см}$*, which was achieved with a sample thickness of 0.033 cm.*

KEYWORDS: *Li-Ion, Polymer Electrolyte (PE), Impedance Spectroscopy, Polymethyl Methacrylate (PMMA), Conductivity.*

1. INTRODUCTION

Today, lithium-ion batteries are used by millions of people in their daily lives. Portable devices are used in laptops, mobile phones, and similar electronic devices because of their lightness, high energy density, and charging capabilities [1]. Polymer-based lithium-ion batteries differ significantly from lead-acid, nickel-cadmium batteries in terms of specific energy, high power density, low cost, light weight, small size. Polymer electrolyte (PE) can have good electrochemical stability and high ionic conductivity [2]. As a result of the use of liquid electrolytes, we can observe the negative effects of solvent evaporation, electrochemical corrosion and leakage, which are greatly reduced by using polyethylene [3]. PE also has properties that are very similar to those of liquid electrolytes and can maintain good electrode-electrolyte contact during battery operation [4]. There are also several types of polymer electrolyte, solid polymer electrolyte, liquid polymer electrolyte, gel polymer electrolyte [5], [6].

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In this work, we investigated the temperature dependence of the electrical conductivity of a solid polymer electrolyte using electrochemical impedance spectroscopy.

2 Experiments

2.1 Technology of electrolyte preparation. First, 2 g of polymethyl methacrylate (PMMA), 1 g of ethylene carbonate (EC), 0.75 g of lithium trifulloromethane ($LiTf_2$) are placed in a beaker, and 40 ml of tetrahydrofuran (THF) is added as a solvent [7]. Stir this mixture for 24 hours at room temperature in an IKA C-MAG until smooth, then pour into an 8 cm petri dish, fig.1 [8]. We place the sample in a Petri dish in a closed container, in a dark place, dry for 24 hours [9]. During the experiments, samples of 4 different thicknesses were taken. Selected electrolyte samples were placed in a circle between special electrodes. The appearance of these samples is shown in Figure 2. Selected electrolyte samples were placed in a circle between special electrodes. The appearance of these samples is shown in Fig. 2.

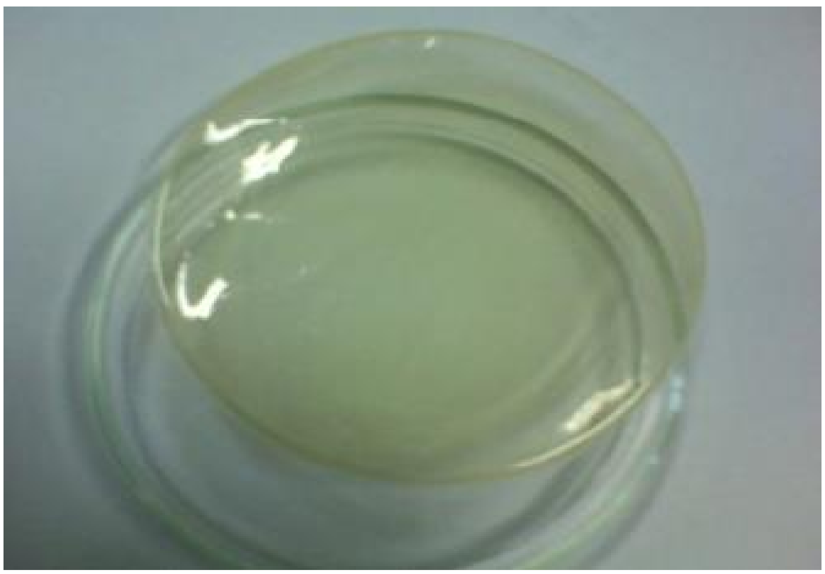

Fig. 1. Ready solid polymer electrolyte

Fig 2. Samples prepared for measurement of electrolytes.

2.2 Measurement method. A convenient way to obtain information about the electrochemical and physical properties of materials using an alternating electric field is called the electrochemical impedance method. Typically, the frequency of the external alternating electric field applied to the sample is in the range from $10^{-6}$to 10^{12} Hz. In this range, one can study the bulk dielectric properties of the sample and the process of electrical conductivity [10], [11]. In our work, this method was mainly used to study the electro physical parameters of electrolytes. The efficiency of known polymer-based lithium-ion batteries depends on the electro physical parameters of a solid polymer electrolyte [8]. Therefore, the ionic conductivity of the electrolyte was checked by electrochemical impedance spectroscopy under the influence of an electromagnetic field with a frequency of 50 Hz to 100 kHz using the Hi-Tester HIOKI 3531 Z [12], [13]. The experiments were carried out with electrolytes of different thicknesses and at different temperatures. It is known that electrical impedance is the impedance of an electrical circuit to a harmonic signal. Electrochemical impedance spectroscopy is one of the most reliable and effective methods for determining the ionic conductivity of liquid electrolytes, condensed salts, ion-conducting polymers and glass [10]. Nyquist coordinates are used in electrochemical impedance studies. In this method, the complex takes the ohmic plane and places the active impedance Z_r along the x-axis and the reactive impedance Z_i along the y-axis, the total resistance in complex form is expressed as follows [14].

$$Z = Z_r - j \cdot Z_i$$

$$Z_r = Z_0 \cdot \cos(\theta) \quad (1)$$

$$Z_i = Z_0 \cdot \sin(\theta)$$

The ionic conductivity s of the sample was calculated using the following formula:

$$\sigma = \frac{l}{RS} \quad (2)$$

where l is the thickness of the electrolyte, *R* is the active resistance of the electrolyte, *S* is the surface of the electrolyte [15].

3 Results. Electrochemical impedance spectroscopy was used to construct a graph of electrochemical impedance spectroscopy of solid polymer electrolytes; it was determined that the electro physical parameters depend on the temperature and thickness of the sample (Figures 3 and 4). As can be seen from Figure 3, the resistance of the solid polymer is 535 ohms at room temperature. It has been found that the ionic conductivity of the electrolyte increases with increasing temperature. Experiments have shown that the ionic conductivity was $6.39 \cdot 10^{-6} \frac{1}{Ом \cdot см}$ at 303K and $1{,}07 \cdot 10^{-4} \frac{1}{Ом \cdot см}$ at 373K. This shows that the conductivity of the electrolyte increases with increasing temperature.

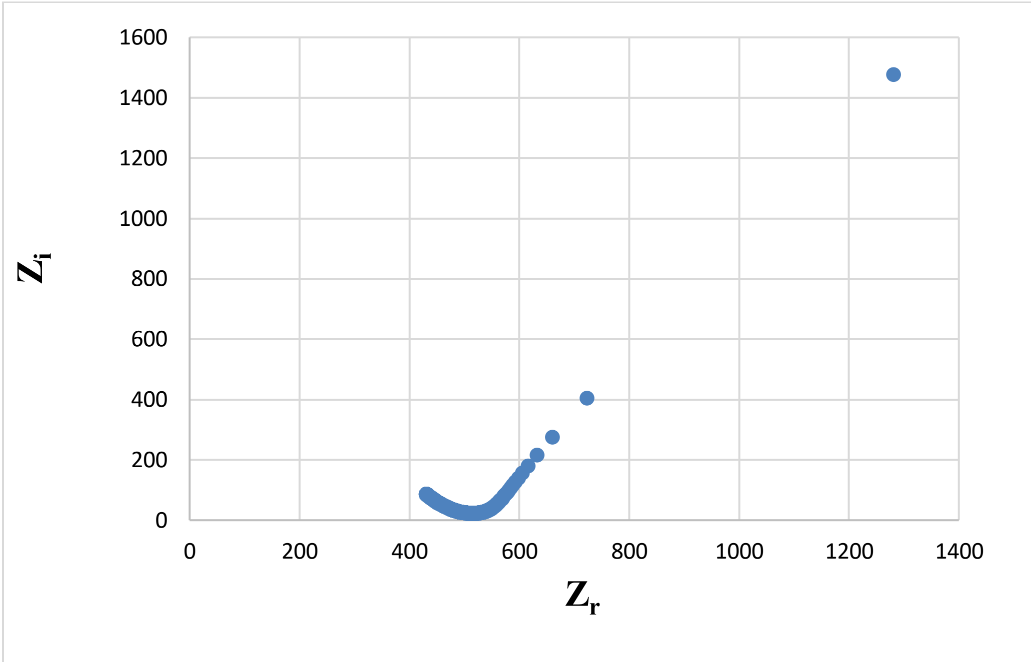

Figure 3. Graph of electrochemical impedance spectroscopy of a solid polymer electrolyte based on LiTf2.

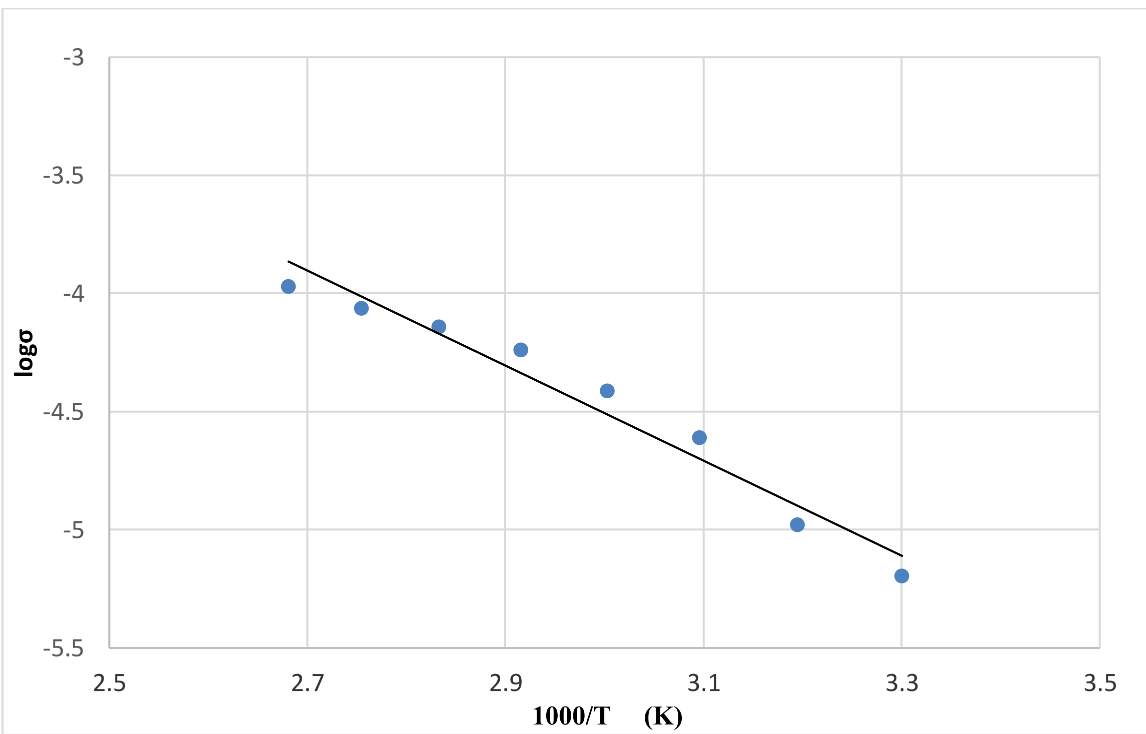

Figure 4. Temperature dependence of the ionic conductivity of a solid polymer electrolyte.

In addition, in this work, in Table 1, the dependence of the resistance and ionic conductivity of a solid polymer electrolyte on the sample thickness was investigated.

Sample	sample thickness(см)	R_b (Ом)	S ($см^2$)	σ ($\frac{1}{Ом \cdot см}$.)
$LiTf_2$-1	0,033	341,46	3,142	3,07587E-05
$LiTf_2$-2	0,0246	714,28	3,142	1,09613E-05
$LiTf_2$-3	0,029	315,55	3,142	2,92498E-05
$LiTf_2$-4	0,023	457,14	3,142	1,6013E-05

As can be seen from the table above, the permeability of the LiTf-1 sample reached its maximum value and amounted to $3{,}075 \cdot 10^{-5} \frac{1}{Ом \cdot см}$.

4 CONCLUSION

The ionic conductivity of solid polymer electrolyte is $6.39 \cdot 10^{-6} \frac{1}{Ом \cdot см}$ at 303K and $1{,}07 \cdot 10^{-4} \frac{1}{Ом \cdot см}$at 373K. When studying the dependence of the electrical conductivity of an electrolyte based on LiTf2 on its thickness, the maximum value was $3{,}075 \cdot 10^{-5} \frac{1}{Ом \cdot см}$,, which is achieved with a sample thickness of 0.033 cm.

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