Impedance Analysis of Heat Treated Polyethylene Oxide Polymeric Material for a Neural Storage Application

Mahmoud Z. Iskandarani
Faculty of Science and Information Technology,
Al-Zaytoonah Private University of Jordan, Post Code: 11191, Amman, Jordan

Abstract: Problem statement: From the early days of, researchers have developed electronic models of neurons designed to emulate neural behavior with electrical signals that mimic in some ways the measured potentials of biological neurons. Researchers interested in fabricating artificial neurons have long sought a simple and techniques to produce devices that efficiently store synaptic weights, which is behind holding a particular state in relation to conductance parameters. As Engineers become closer to realizing accurate hardware models of neurons, the need for a simple analog memory device grows correspondingly. To determine the storage characteristics of polyethylene oxide based polymer as the base material for high charge storage analogue neural switch. Approach: Various devices prepared under controlled conditions. Each device tested for its impedance characteristics as a function of both frequency and temperature. Mathematical model developed to account for the obtained characteristics. Results: The heat treated devices showed stability, repeatability and ability to store enough charge for long time periods. Impedance analysis proved a similar response to the actual neural switches. Conclusion: The symmetrical behavior for such devices opened a wide application area for the manufacturing of low and high frequency analogue devices for intelligent system applications.

Key words: Neural, modeling, memory, information processing, polymers, storage

INTRODUCTION

The design of an artificial neural device can help in future implementations and studies in the fields of memories, neural networks, intelligent computers and medical applications to name a few. The design and implementation provides a good insight into the process of combining high charge storage materials to produce intelligent switching elements. Such devices may be used to control and modulate the communication between different artificial neurons.

Solid polymer electrolyte systems have been widely used as potential technological applications in energy and charge storage. It is apparent that these materials show ionic conductivity when ionic salts are dissolved in them. The mechanism of ionic mobility is still controversial.

Amorphous polyethylene oxide based materials doped with alkali-metal salts are favored candidates for use as electrolytes in solid-state rechargeable storage medium. Among others, a highly attractive avenue to achieving both high ionic conductivity and dimensional stability consists in covalently bonding an amorphous low glass transition temperature PEO-based polymer to a second polymer, thereby forming a block copolymer. Such a copolymer will either be segmentally mixed disordered or microphase separated ordered into periodically spaced nanoscale domains of the different blocks, with the covalent junction residing at the interface.

Polymers carrying electronegative atoms oxygen or nitrogen in their repeat unit can act as solvents for certain salts, as a consequence of the attractive interaction between cations and the polymer. A prototype class of such polymer electrolytes are polyethers, e.g., polyethyleneoxid (PEO), complexed with Li salts that contain a highly polarizable anion. These materials can show significant ionic conductivities offering applications as electrolyte material in rechargeable lithium-polymer storage media\textsuperscript{[1-5]}.

Background: Ethylene oxide (CH\textsubscript{2}CH\textsubscript{2}O) is highly reactive with particular importance as a chemical intermediate due to the tendency of the ring to open in the presence of ionic catalyst. Co-dissolving an alkali metal salt with PEO [HO(CH\textsubscript{2}CH\textsubscript{2}O)\textsubscript{n}H] and removal of the solvent will result in a mixed phase system which retains, in part, a complex of the polymer and the salt. It is shown that the paired ether oxygen electrons, which give the polymer strong hydrogen - bonding affinity, can also be involved in association reactions with a variety of monomeric and polymeric electron acceptors with polymer-alkali salts recognized as fast ionic.
conductors with wide charge storage using them as solid electrolytes in batteries, chemical sensors and other applications[6-12]. For pure PEO the crystalline phase occupies approximately 80% of the available volume, with the remainder being taken up by a dispersed amorphous phase. On addition of LiCF₃SO₃, Li⁺ ions form cross-links between ethylene oxide segments of neighboring chains as the cation (Li⁺) forms ionic bonds with the negatively polarized oxygen atoms forming a closed helical structure with the Li⁺ ions inside. The CF₃SO₃⁻ anion forms another ionic bond with the methylene group outside the helical structure when the ring structured monomers. It is suggested that ionic conduction in PEOxLiCF₃SO₃ occurs by the cation (Li⁺) hopping between sites in either the single or double helix structures. However, this hopping model was discredited by studies, which showed the ionic conductivity occurred mainly in the amorphous phase rather than in the crystalline phase. Furthermore experiments with dopant ions that form immobile ion pairs indicated that transport was not occurring down a helical path. A variety of experiments showed that ion transport in the majority of the polymer-salt complexes occurs through segmental motion of the polymer[13-15].

MATERIALS AND METHODS

Polymer films were prepared using poly (ethylene oxide) with average molecular weight of 5×10⁶ Daltons (Da) and density of 1.21 at 65°C and lithium trifluoromethane sulfonate 97% pure. The required amounts of lithium salt and polyethylene oxide (PEO), to give an O: Li ratio of 10: 1, were dissolved in acetonitrile 99% pure under nitrogen atmosphere. The solution was then stirred at room temperature for 48 hours after which the solution was filtered to remove any un-dissolved materials and stored in 14, 2 mL plastic containers and kept well isolated from the atmosphere.

The polymeric films were deposited using a drop coating technique and then dried by heating for 30 ands in an oven at 50°C.

RESULTS

Figure 1 shows the complex impedance of a heat treated device as a function of frequency.

Both real and imaginary parts of the complex impedance behave in a symmetrical but opposite manner as a logarithmic function of frequency, where at any value within a range of frequencies the product of the real and imaginary parts is negative. As the real part is positive and decreasing with frequency while the imaginary part is negative and increasing with frequency, then a model which readily presents itself is a parallel combination of a resistor and capacitor with no evidence of a double layer capacitance as the plots representing the real versus the imaginary parts, as shown in Fig. 2, do not show a spur at low frequencies, with Fig. 3 showing an important Frequency-Temperature characteristics.

DISCUSSION

Complex impedance characterization was carried out to determine the device response.
The real and imaginary parts of the complex impedance function can be obtained as follows:

\[ Y = G + j\omega c = \frac{R + j\omega cR}{R} \]  
\[ Z = \left[ \frac{R}{1 + j\omega cR} \right] = \frac{R (1 - j\omega cR)}{(1 + j\omega cR)(1 - j\omega cR)} = \frac{R - j\omega cR^2}{1 + \omega^2 c^2 R^2} \]

So:

\[ \text{Re}(Z) = \frac{R}{1 + \omega^2 c^2 R^2} \]  
\[ \text{Im}(Z) = \frac{\omega c R^2}{1 + \omega^2 c^2 R^2} \]

where, \( \omega_c \) is the crossing frequency of the zero frequency axis. Further analysis showed that both real and imaginary parts would intersect at angular frequency \( \omega_c \) given by:

\[ \omega_c = \left( \frac{3}{2} \omega_0 \right) \]

Analysis of the device characteristics showed a non-Arrhenius temperature dependence of the device conductance which indicates that the conductivity behavior of PEO_{10}LiCF_3SO_3 is governed by much more complicated form of dynamics with obvious dependency of both the real and imaginary parts on frequency. The impedance characteristics were very encouraging in terms of neural storage application, which uses analogue logic activation signals and respond to temperature and frequency in a symmetrical manner.

**REFERENCES**


