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Capacitive Sensor based on Self-healing Ionic conductive hydrogels for Human Motion Detection

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Summary:

Poly (ethylene oxide) (PEO), known for its self-healing properties through hydrogen bond-forming hydroxyl groups, was used to synthesize hydrogels, and lithium bis (trifluoromethane sulfonyl) imide (LiTFSI) was added to impart ionic conductivity. The manufactured hydrogels were analyzed to evaluate their mechanical properties, self-healing abilities, and electrical characteristics. Based on these analyses, a self-healing capacitivie sensor was fabricated, which utilizes the unique properties of the hydrogel to monitor human movement.

Keywords: Hydrogel, self-healing, capacitive sensor, wearable sensor, human motion

Background, Motivation an Objective

Recently, flexible electronic devices have garnered significant attention due to their potential applications in diverse fields, including wearable sensors, energy storage devices, actuators, and soft robotics engineering [1]. However, these devices can undergo performance degradation from deformation or damage during use, leading to potential malfunctions. Consequently, the integration of self-healing capabilities, encompassing mechanical, electrical, and chemical properties, becomes vital to address scratches or mechanical damages. Ionic conductive hydrogels are regarded as ideal materials due to their distinctive 3D network structure, which arises from the physical or chemical crosslinking of polymers. This structure imparts elasticity and concurrently facilitates a favorable environment for ion movement. Furthermore, this material is recognized as a highly attractive substance due to its straightforward manufacturing process, cost-effectiveness, and high conductivity, along with its self-healing capabilities. In this study, we manufactured hydrogels using poly (ethylene oxide) (PEO) known for its effective self-healing properties through hydrogen bond-forming hydroxyl groups [2], and we introduced lithium bis (trifluoromethane sulfonimide) (LiTFSI) to impart ionic conductivity. The mechanical properties, self-healing ability, and electrical characteristics of the manufactured hydrogel were analyzed. Furthermore, finite element analysis will be utilized to establish the correlation between motion-induced mechanical modification and its corresponding changes in capacitance. Informed by these analysis results, we fabricated a self-healing capacitor sensor. This wearable sensor, leveraging ionic conductors, was subsequently tested in practical applications by recording capacitance variations to monitor human movement.

Description of the New Method or System

Hydrogels were synthesized using PEO, which possesses self-healing properties due to its hydroxyl groups forming hydrogen bonds. Ionic conductivity was imparted by adding LiTFSI. The self-healing properties between the produced poly (acrylic acid) (PAA)-PEO hydrogel and PAA-PEO-Li ion conductor were evaluated. Based on the analysis of these properties, a self-healing capacitive sensor was designed to monitor human movement by using the PAA-PEO-Li ion conductor as the upper and lower electrodes and the PAA-PEO hydrogel as the dielectric layer, with the interfaces connected through their self-healing capabilities.

Results

The self-healing elastomer was synthesized by combining high molecular weight PAA and PEO based on hydrogen bonding interactions. For the manufacturing of ion conductors, the electrolyte salt LiTFSI was chosen due to its high solubility in various solvents and polymers. The content of LiTFSI was varied to adjust the characteristics of the ion conductor. Additionally, to manufacture a simple ion conductor through photoinitiated polymerization, the photoinitiator Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide (TPO) was added, and after UV exposure, the sample was placed in a constant temperature and humidity chamber to remove excess moisture and form a PAA-PEO hydrogel through hydrogen bonding.

The electrolyte salt LiTFSI doped in the ion conductor can move within the polymer network, granting high ionic conductivity to the ion conductor. The Nyquist plots of the ion conductor are displayed in Figure 1 and Table 1, as obtained through EIS tests. The ionic conductivity was calculated using equation (1), where L is the thickness of the sample, R is the bulk resistance obtained from the Nyquist plot of the impedance spectrum, and S is the cross-sectional area of the ion conductor. As seen in Figure 1 and Table 1, an increase in the LiTFSI content leads to enhanced ionic conductivity of the ion conductor.

$$\sigma = \frac{L}{RS} \quad (1)$$

To evaluate the self-healing behavior of the PAA-PEO hydrogel, rectangular bar-shaped samples of PAA-PEO and PAA-PEO-Li ion conductors measuring 10x40x2 [mm] were cut in half. The two pieces were compressed and cultured in a constant temperature and humidity chamber (25°C/90%). To utilize the self-healing properties in manufacturing a capacitive sensor, one side was compressed with the PAA-PEO hydrogel without the electrolyte salt, and the other side with the PAA-PEO-Li ion conductor containing the electrolyte salt. After healing for a certain period, the healing properties of the samples was assessed. It was confirmed that both the PAA-PEO hydrogel without electrolyte salt and the PAA-PEO-Li ion conductor pieces with electrolyte salt possessed self-healing properties. Additionally, it was confirmed that self-healing properties exist between the PAA-PEO hydrogel and the PAA-PEO-Li ion conductor pieces. This confirms the feasibility of manufacturing a capacitive sensor using self-healing properties.

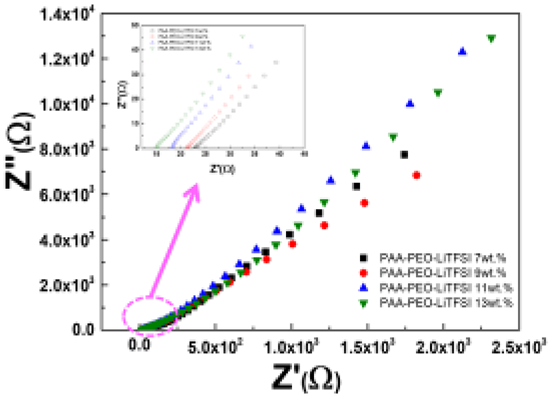

Fig. 1. Nyquist plot of impedance spectra of the PAA-PEO-Li ionic conductors with various LiTFSI content.

Tab. 1: Impedance and ionic conductivity of the PAA-PEO-Li ionic conductor with various LiTFSI contents

LiTFSI (wt.%)	Resistivity (Ω)	Ionic conductivity (S/cm)
7	22.87	1.93×10^{-3}
9	21.20	2.09×10^{-3}
11	18.07	2.45×10^{-3}
13	15.06	2.94×10^{-3}

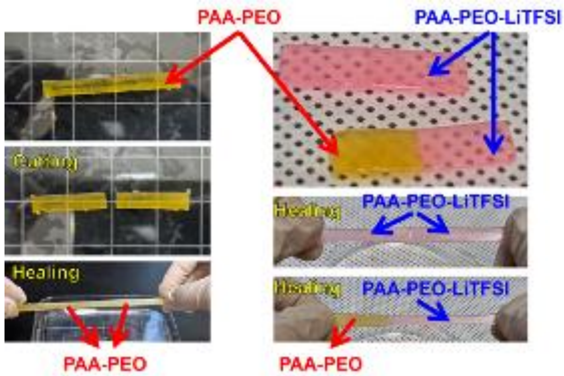

Fig. 2. A self-healing test: conducted by cutting the middle of a bar-shaped sample, reattaching it, and then pulling it apart.

References

[1] B. C. K. Tee, C. Wang, R. Allen, Z. Bao, An electrically and mechanically self-healing composite with pressure-and flexion-sensitive properties for electronic skin applications, *Nature nanotechnology* 7(12), 825-832 (2012); doi: https://doi.org/10.1038/nnano.2012.192

[2] J. Li, Z. Wang, L. Wen, J. Nie, S. Yang, J. Xu, S. Z. D. Cheng, Highly elastic fibers made from hydrogen-bonded polymer complex. *ACS Macro Letters 5*(7), 814-818 (2016); doi: https://doi.org/10.1021/acsmacrolett.6b00346