

Recent developments in ionogel-based stretchable electronics

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Abstract

This review will go over the potential ionogels hold in the future of stretchable electronics in terms of its fabrication, capabilities, and application. The studies in this review focus on ionogels' cost effectiveness, different types of manufacturing, various mechanical properties, and proof of concept devices that show potential applications.

1. Introduction

Stretchable electronics have become an important area of research as further technological developments allow for the integration of electronic devices in more diverse ways [1]. One such avenue for stretchable electronics is ionogels, which consist of an ionic liquid incorporated into a polymer matrix. The ionic liquid allows the material to be conductive, as ions conduct electricity by moving in response to an electric field. The matrix provides desirable mechanical properties, depending on the polymer. Such properties could include varying amounts of stretching, flexibility, thermal stability, self-healing, transparency, and more [2–4]. Researchers are exploring different ways to manufacture these types of devices, such as with 3D printing and photolithography in order to create more complex structures [5–8]. The applications for these devices have been looked into for various types of sensors and nanogenerators [2, 3, 9–11]. Ionogels are especially appealing for their low cost of materials and manufacturing, low environmental impact, as well as the range of properties offered due to the variety of polymer matrices available [4, 10].

This review will specifically go through the methods and cost of bulk production, photolithography, and 3D printing of ionogels. Additionally, their properties and potential applications will be discussed.

2. Fabrication

2.1. Bulk Production

The most basic form of the ionogel would be to make it in bulk using a simple mold to pour in the ionogel solution and then let cure [2–4]. This was done for most experiments that tested only the ionogel properties, without much focus on the structure of the gel. Variations on the chemical compounds used and procedure depend on the experiment, such as with Dang et al. where α -lipoic acid, a biological molecule, was added to make the gel rehealable and recyclable [4]. Another self-healing ionogel was developed by Zhang et al. based on Fe_3O_4 nanoparticles coated with poly(acrylic) acid that gave the self-healing property due to the $\text{Fe(III)-O}_{\text{carboxyl}}$ bond [2].

2.2. Photolithography

Photolithography is one method that would provide more complex ionogel structures. Zhong et al., for example, produced micropatterns through photolithography, where the ionogel solution was spin-coated onto a substrate, then selectively cured using UV radiation [6]. The process was repeated to create detailed 3D structures.

2.3. 3D Printing

3D printing ionogel-based strain sensors was developed by Crump et al. by making a gel of reduced graphene oxide

dispersed into the ionic liquid 1-butyl-3-methylimidazolium tetrafluoroborate ([BMIM][BF₄]) [8]. They then 3D printed the sensor onto and encapsulated it with polydimethylsiloxane. Wong et al. made an ionogel with a photoradical generator and a dissolved polymer in [BMIM][BF₄], so that they could induce photoradical polymerization and cross-linking via UV radiation after printing their structure [5]. They printed the gel in bulk, as well as in an auxetic structure, which exhibits a negative Poisson ratio, showing that complex shapes and structures could be achieved with 3D printing that could add to an electronic device's capabilities.

2.4. Cost

Another attractive quality of ionogels is the low cost of manufacturing and materials, with most articles emphasizing this point as a motivation for pursuing ionogel research. Netto et al., for example, stated that all chemicals used to make their gas sensor was commercially available, and cost merely US\$1 to make a single sensor [10]. Crump et al. also stated that their fabrication method was relatively cheap compared to alternative deformable non-flowing conductors, at \$3 per mL compared to liquid metals at \$70.25 per mL. Therefore, it can be seen that ionogels provide easily manufacturable, low cost electronic devices, that can be formed into complex shapes with tunable properties.

3. Capabilities

The range of strain for ionogels vary greatly from experiment to experiment, and highly depend on the polymer matrix. At the lower end of the spectrum lie the photolithographically fabricated ionogels with a thiol acrylate polymer, having an ultimate strain of 20-50%, depending on the methacrylate content [6]. 3D printed ionogels with the composition described above lie slightly above, with around 300% strain [5, 8]. The highly stretchable ionogels tend to be those with self-healing capabilities, reaching around 1000% strain, with Zhang et al. reaching 2000% strain [2-4]. Ionogels offer a wide range of stretchability, with the ability to choose which composition would provide the best fit for the application. The range of useful temperature is also beneficial for ionogels, especially compared to other possible stretchable conductive materials, such as hydrogels where its water content either evaporates or freezes [3]. Ionogels are able to operate at temperatures between -20°C and 100°C, making it more widely available for different environments.

The durability of the ionogels have also been tested with cyclic testing, storage life, and reusability. Several papers have been published about self-healing ionogels, which offer great potential for long lasting ionogels. The healing efficiency is reported by Dang et al. to be about 96% electrically, and 86% mechanically, indicating that the ionogel kept most of the conductivity and mechanical properties it originally had [4]. Cyclic testing of ionogels showed little to no change in performance, indicating that they are able to have a long lifetime without being replaced, demonstrated in [2, 4, 8, 10]. Storage life is also not a concern, as Netto et al. reported no degeneration in performance over

6 months, and pointed out the cheap cost of replacing a sensor (\$1) [10]. Dang et al. also showed promising results with recycling/reusing the ionogel with their sensor, as they are able to reform the gel through a heating process, effectively forming a liquid again that could be reshaped or made into an adhesive [4]. There is great potential for ionogels in terms of reducing their environmental impact by having an increased durability and recyclability.

4. Applications

Specific applications of ionogels include sensors and nanogenerators. The sensors function on a basic concept: disruption of conductive channels resulting in a detectable electrical response. Strain sensors, for example, can detect strain as a function of resistance of the ionogel, based on the principal that strain changes the length and cross-sectional area of the gel, affecting the resistance [2, 5]. Other types of sensors have also been fabricated, such as an air flow sensor and a gas sensor. The air flow sensor works with a biomimetic 'hair' that moves in air flow and deforms the ionogel it sits on, relaying an electronic signal to show how much air flow it detected and in which direction [9]. This was made for unmanned aircraft vehicles, optimal due to its flexibility and ease of manufacturing. Gas sensors work similarly, with certain compounds changing the conductance of the sensor thereby relaying an electronic signal [10]. Ionogels can also be used to make nanogenerators, which work with the triboelectric effect, where mechanical deformation leads to generation of currents [3]. This makes it ideal for use in electronic skins, and soft robotics.

5. Conclusions

In the field of stretchable electronics, ionogels are a strong contender for the ideal material as they have a wide range of customizable mechanical properties, high thermal stability, high durability, with low cost and simple manufacturing methods. Many different avenues for ionogels have been and can continue be explored, from incorporating self-healing properties to manufacturing complex structures to innovating applications that can best use this material. Current challenges include moving past mere proof of concept builds into producing something manufacturable, as well as finding ways to tune the ionogels' properties to optimally match the application. Ionogels offer great potential for the future of electronic devices and their incorporation into our daily lives.

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Conflict of Interest

Author has no conflicts of interest.

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