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Proceeding Paper

Polymeric Ionic Liquids as Effective Biosensor Components †

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Abstract

The unique properties present great prospects for polymeric ionic liquids (PILs) research in these areas, where progress and breakthrough technologies can be expected in the coming years. This brief review examines the latest work (2024–2025) and the prospects for using PILs as an effective component of sensor-related devices for medical or biological applications. Potentially, the PILs-based sensors can detect various movements in real time, which are necessary for high-performance wearable sensor platforms. The artificial electronic skin demonstrates high potential not only as a recording of body signals, but also as an effective wound dressing. The polymer actuators with PILs are indispensable in many applications.

Keywords: polymeric ionic liquids; sensors; electronic skin; dielectric elastomer actuators

1. Introduction

This brief review contains the latest work (2024–2025) and prospects for the use of polymer ionic liquids as effective components of devices related in one way or another to sensors for medical or biological applications.

Poly (ionic liquids) (PILs) are polymeric ionic liquids or polyelectrolytes that contain a polymer base and contain fragments of ionic liquid in each of the repeating units [1]. According to a more precise definition, PILs are ionic polymers with full ionization. The breadth of PILs applications is presented in recent reviews by the authors [1,2] and is illustrated in Figure 1.

We identify three of the most promising applications related to bioactive sensors, namely, the medical applications, the creation of electronic skin, as well as the actuators in the dielectric elastomers.

Multidimensional sensor devices based on PILs are extremely promising for the development of high-performance screening in the field of environmentally friendly chemistry and biology, while providing easier identification of a variety of analyzed substances.

In a more expanded version, some applications can be found in a recent review [3], which examines ionically conductive hydrogels, which include PILs.

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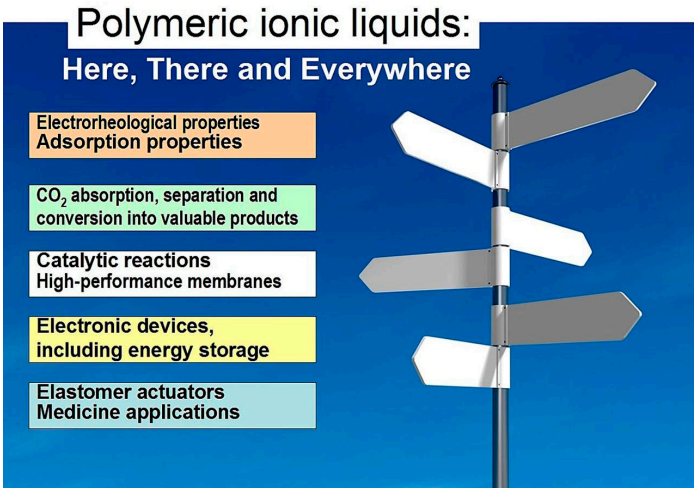


Figure 1. The range of modern applications of poly-ionic liquids according to the work [2]. Reproduced from [2] with permission from Elsevier, 2024.

2. PILs in Medicine

Flexible and transparent humidity sensors based on superbranched polymers (ionic liquids) for wearable use were synthesized and investigated in [4]. Usually, low sensitivity to humidity and mechanical inflexibility interfere with normal operation. This study was based on a branched poly (ionic liquid) based on imidazolium (HPIL). And the efficiency of this device has been significantly improved by regulating antianions such as trifluoromethanesulfonimide ion ($TFSI^-$). This sensor shows good linearity and excellent sensitivity to bending humidity, as well as mechanical stability in an almost absolute range (6% to 98%) of relative humidity. The authors note that the sensor they synthesized (PHIL-TFSI) opens a new path to the creation of high-performance wearable sensor platforms [4].

By varying the ion content in PILs, the ion gels also exhibit good adjustable hydrophilicity/hydrophobicity and adaptability to the environment. Recent work [5] has focused on gradient ionogels for the skin, induced by an electric field, for hypersensitive and ultrafast multifunctional sensors. Potentially, such sensors can detect various movements, such as detecting liquid droplets, detecting human joint movements, and monitoring the pulse wave in real time (Figure 2). Based on the gradient strategy, the flexible ionogel-based sensor now demonstrates high sensitivity of up to 1.0 kPa^{-1} and a low minimum detection threshold of up to 0.15 Pa and a wide temperature range. The fast response time was 8 ms, with a durability of more than 5000 cycles. More importantly, the studied and fabricated basis of high-resolution pressure sensors makes it possible to accurately output three-dimensional pressure distribution maps [5].

It is known that the problem of peptide preparations is permeability, and stability too, which is a serious barrier to the preparation of medicines in the field of local delivery. To solve this problem, a bioactive supramolecular ionic liquid was designed, which could create an effective delivery system for self-assembling peptide drugs by increasing the total absorption of snake venom peptide, which has a good anti-wrinkle effect and reduces the area and volume of wrinkles around the eyes [6]. The effectiveness of the action was well supported and justified by quantum chemical calculations and homology modeling (Figure 3).

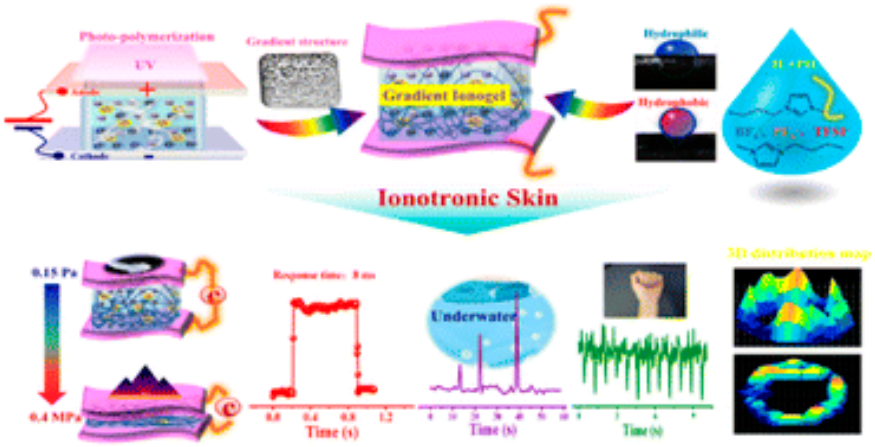


Figure 2. Range of applications of PILs-based sensors according to work data [5]. Reproduced from [5] with permission from RSC, 2025.

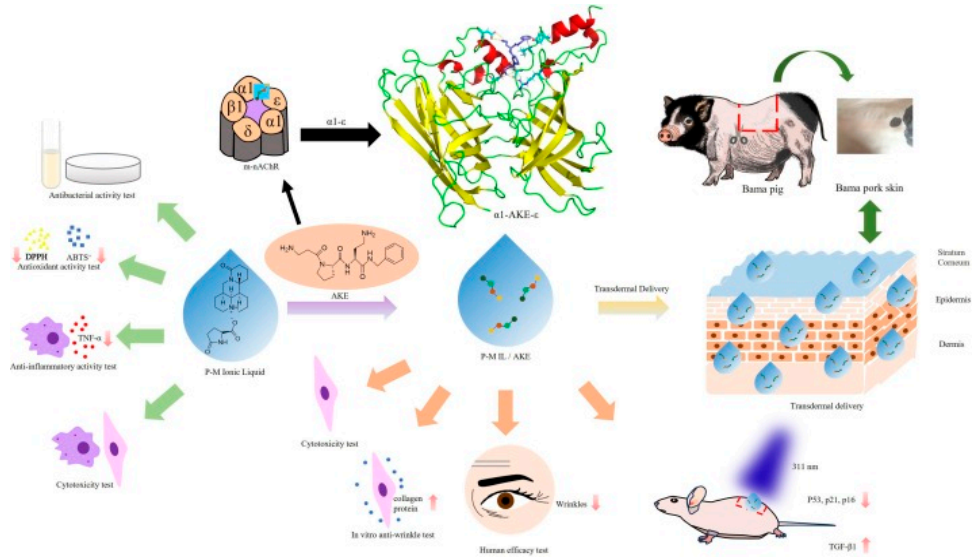


Figure 3. The way to create a wrinkle reduction drug with the active use of PIL according to the work [6]. Reproduced from [6] with permission from Elsevier, 2024.

It has recently been found that a hydrogel based on PIL accelerates the healing of diabetic wounds [7]. Bacterial colonization, abnormal inflammatory reactions, and impaired angiogenesis create strong barriers to diabetic wound healing. The studied hydrogel (CA-PIL/POD) can significantly accelerate the elimination of diabetic wounds by increasing collagen deposition, enhancing angiogenesis, and also by reducing the expression of inflammatory factors. The authors of [7] claim that this study makes it possible to create a new and effective bandage for healing chronic wounds with promising prospects for clinical use and implementation in practice.

PILs modifier as an ion-induced crosslinker and functional enhancer at facile fabrication of multifunctional gelatin hydrogels for flexible electronics was studied in the work [8]. Inspired by the ion-induced salting-out effect and the tunability of polymeric ionic liquids, poly(1-vinyl-3-carboxymethyl imidazolium fluoride) was synthesized as an advanced macromolecular modifier and employed in a one-step soaking method to construct gelatin-based ionically conductive hydrogel. The PIL demonstrates biocompatibility, thermosensitive adhesion, and frost resistance, also applied in wearable sensors, achieving high sensitivity with gauge factor of 3.94.

Imidazolium-based poly(ionic liquid)/poly(vinyl alcohol) multifunctional supramolecular gels with self-healing, shape memory, and strain sensing have been synthesized and studied in [9]. An ionic liquid monomer was synthesized and polymerized to produce a corresponding PIL. The gels had excellent electrical conductivity, high strength, self-healing ability, and redox effect of shape memory. The authors of the paper note that the healed PILGs sensors could monitor the human joint movement, facial expression, and speech recognition, etc. The one-step solution gel transition strategy will provide a universal approach for preparing multifunctional gels, which have great potential in strain sensors, soft electronic materials, and portable testing equipment, etc.

3. PILs as Electronic Skin

PILs can also be considered an ionic skin. These are self-healing materials that allow partial or even complete self-healing after damage and essentially mimic natural systems. Such sensors are beneficial to monitoring human body movement.

Recently, the authors of [10] reported on the uncomplicated fabrication of a carboxymethylchitosan/dextran/PIL-based hydrogel with characteristic antibacterial and antioxidant properties to accelerate the healing of the skin wounds. The POCP-composite hydrogel was obtained by introducing PILs poly (1-butyl-3-vinylimidazolium gluconate) with gluconate as a counterion into a hydrogel based on carboxymethyl chitosan and oxidized dextran based on phenylboronic acid. The gel meshes, give the material an excellent self-healing ability and thus help to adapt to the shape of the wound. The authors of the study [10] claim to present an effective drug-free strategy for the preparation of hydrogel dressings with various properties capable of clinical wound treatment.

Radiation synthesis of ionogels based on ionic liquids with rapid self-healing and environmental resistance was used to synthesize multifunctional ionic skin. The authors of [11], inspired by human skin, have successfully synthesized a fully ionic liquid ionogel based on a covalently/non-covalently bonded ionogel, which they named as I-Skin. The properties of the resulting material make ionogels well suited for use in multifunctional measurement systems such as strain, temperature, and humidity measurement, recording measurement and matrix determination (Figure 4).

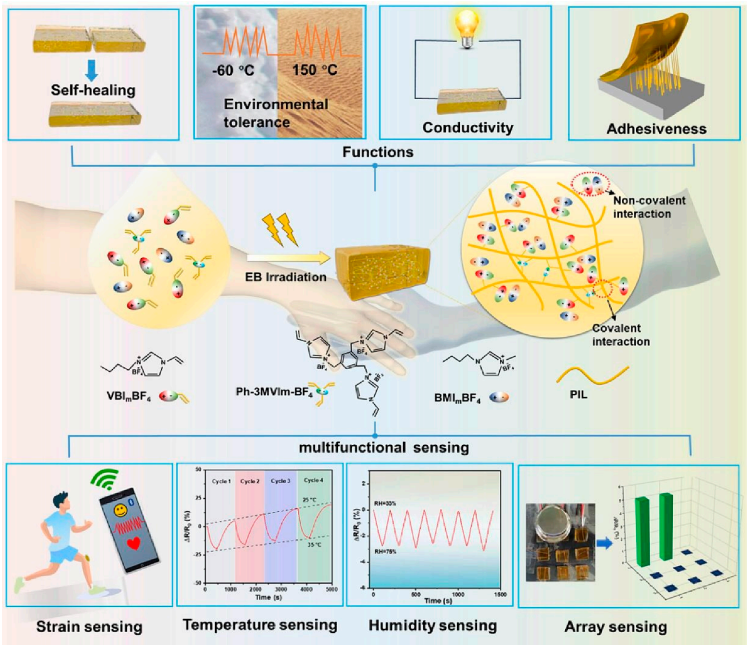


Figure 4. Synthesis and application of I-Skin according to the work [11]. Reproduced from [11] with permission from Elsevier, 2024.

It is obvious that infections can interfere with the healing process and become a life-threatening pathology, especially due to increased bacterial resistance. Hydrogels can successfully solve this problem due to their unique capabilities and versatility. In the study [12], a double-acting hydrogel consisting of methacrylate gelatin as a matrix and an anion-exchange polymeric salicylate ionic liquid was considered for anti-inflammatory and antibacterial activity. It should be noted that hydrogels based on natural polymers are particularly suitable because they resemble the extracellular matrix and mechanical properties of natural tissues. The antibacterial ability characteristic of PIL has been tested using the example of Staphylococcus aureus and *E. coli*, which confirms its high potential as a wound dressing (Figure 5).

The authors of [12] believe that this is the first recorded hydrogel containing an anion-exchange polymerizable ionic liquid, which is capable of stimulating the differentiation of macrophages into a reparative phenotype, reducing the level of proinflammatory cytokines while demonstrating antibacterial activity. These features open up wide possibilities for the use of this hydrogel as a promising dressing.

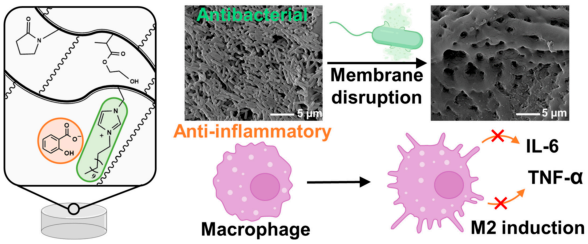


Figure 5. An illustration of the fabrication and activity of PIL-based material according to the research data [12]. Reproduced from [12] with permission from Elsevier, 2025.

4. PIL Actuators in the Dielectric Elastomers

These substances and materials are necessary for soft robotics and medical purposes and are being actively improved at the moment. Development and progress in this area are directly related to decision making. The latest research is now focused on the synthesis and testing of more advanced actuators fabricated from PIL–dielectric elastomers.

Recently, the authors of [13], systematically investigated the effect of ions and electrodes on the operation of ion electroactive actuators. These results provide valuable information for the development of high-performance electromechanical systems with various applications, from soft robotics to tactile interfaces. The Li^+-based liquid crystal polymer composite actuator with poly(3,4-ethylenedioxythiophene) polystyrene sulfonate electrodes demonstrated the highest bending strain, reaching a strain of 0.68% and demonstrating a wide frequency response of up to 110 Hz with a peak-to-peak offset of 3 μm. And the actuator made of a composite material based on an ionic liquid, liquid crystal, and polymer with activated carbon electrodes demonstrated a bending response at a maximum frequency of 50 Hz and a force of 0.48 mN without the phenomenon of reverse relaxation (Figure 6).

The study [14] shows that simultaneous galvanostatic electrogeneration of polypyrrole (PPy) and polyanion, or polycation, from corresponding solutions of pyrrole and monomeric ionic liquids leads to the formation of films from two interpenetrating polymer networks: polyanion-PPy (PILA-PPy) and polycation-PPy (PILC-PPy). Linear activation was characterized by cyclic voltammetry and chronoammetry in an aqueous electrolyte, describing the cationic actuation of PILA-PPy actuators. The PILC-PPy deformation was 8.7%, and the stress gradient was 1.45 MPa, which is 1.5 times greater than that of PILA-PPy actuators, with a higher charge density, 2.1 times better conductivity, and 1.3 times higher

diffusion coefficients. The stability of the actuators has been the subject of special study and was obtained by sequential activation.

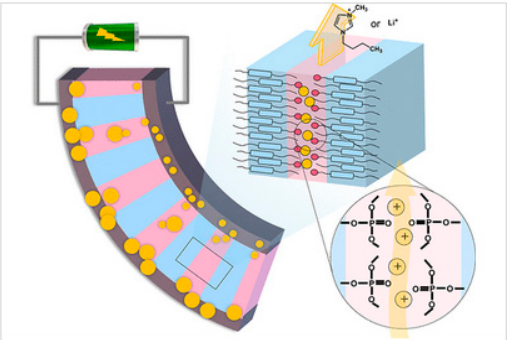


Figure 6. Visual demonstration of the operation of the actuator according to the work [13]. Reproduced from [13] with permission from ACS, 2024.

The authors of [15] presented studies on a transparent hybrid (ionic and dielectric) gel actuator system based on vinyl chloride and ionic liquid with dibutyladipate as a plasticizer. The system operates at a low applied voltage (10–20 V), and the total transmission coefficient at visible wavelengths (450–700 nm) is >85.5–88.5% for all types of IL. Such transparent, flexible, and also durable gels have significant potential as natural materials for wearable and transparent electronic and energy conversion devices.

In study [16], a hybrid electrolyte design was developed based on nanoparticles grafted onto a block copolymer with high ionic conductivity, with conductivity conducted by a single ion. By applying poly (methyl methacrylate) as a neutral base layer to nanoparticles and sequentially polymerizing poly (1-vinylimidazolium bistriflimide) as a charged component, hybrids of copolymers with a good charge gradient and particle dispersion were obtained. Polymer chains of the hybrids irreversibly rearrange and polarize under the influence of applied electric fields, which dramatically increases ionic conductivity. The authors of [16] emphasize the critical importance of polymer hybrid structures for improving ion conductivity, which in turn demonstrates practical information for applications in electroactive actuators, biomedical devices, wearable sensors, and electrochemical devices such as capacitors and batteries (Figure 7).

As such, the actuator systems are one of the most notable aspects of the rapidly expanding field of multifunctional as well as intelligent materials related to PILs. PILs are a particularly relevant and sought-after option for the development of hybrid materials for actuator applications. PILs are capable of having a significant impact on a number of areas of the applications [17].

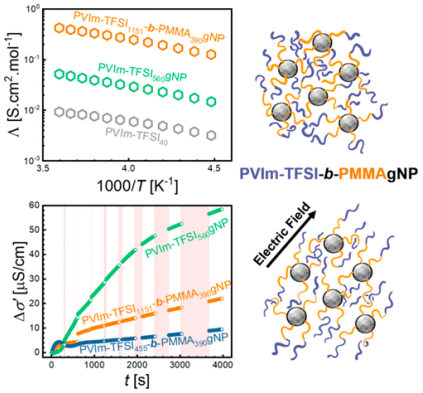


Figure 7. Demonstration of polymer chains of the hybrid irreversibly rearrange and polarize under the influence of applied electric fields, which dramatically increases the ionic conductivity. Reproduced from [16] with permission from ACS, 2025.

5. Conclusions

The unique properties, such as excellent biological (antibacterial, antimicrobial), chemical (high chemical stability), physical (mechanical strength, thermal stability, good adhesion), electrochemical stability, and manufacturability, present great prospects for PIL research in these areas, where progress and breakthrough technologies can be expected in the coming years.

- Potentially, PILs-based sensors can detect various movements such as loads, detect human joint movements and monitor heart rate in real time, creating huge prospects for the use of high-performance wearable sensor platforms. In addition, an effective drug delivery system that increases total absorption using PILs can serve as a reliable option to solve this problem.
- Artificial electronic skin based on PILs demonstrates high potential not only as a registration of body signals, but also as an effective wound dressing with a high antibacterial effect. The problem of durability and stability of such materials can and should be solved in the coming years.
- Polymer actuators are indispensable in many applications, and the use of PILs is an appropriate approach for developing electric actuators capable of meeting a wide variety of application requirements in terms of force, strain, and click time. Currently, further thorough research and fabrication is needed to fully understand the characteristics of the actuator, in particular, the force generated, and the stability of the actuators over time, and to relate this behavior to the sizes of cations and anions. PILs is a particularly relevant and in-demand component for the development of intelligent hybrid materials for use in the actuators, as they are relatively simple to prepare and have a number of individual characteristics. Printing technologies are possible and necessary not only for implementation in real-world applications, but also for increasing scalability.

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