Ion-conducting membranes based on gelatin and DNA

Agnieszka Pawlicka, Alessandra Firmino, and James Grote

The favorable properties of polymer electrolytes made from natural products render these materials good candidates for application in optoelectrochemical devices.

Electronic devices such as mobile phones, laptops, audio players, and other portable media have proliferated in recent years. Owing to the rapid development of the telecommunications industry, this trend is likely to continue. It has also spawned a very active area of research in the production, storage, and distribution of power, preferably at low cost. To make that a reality, new materials will be needed to replace traditional metals, ceramics, and synthetic polymers. In particular, natural polymers have strong potential as substitutes for their synthetic counterparts.

Many displays and batteries are electrochemical devices containing electrolytes (i.e., nonmetal electrical conductors), which can be solids, liquids, gels, ceramics, polymers, or combinations of them. Polymer-based electrolytes offer some advantages over liquid ones, such as higher operating temperature, no flow or corrosion following damage, and practicality. A typical system is a solid or gel ion-conducting membrane consisting of a salt—e.g., lithium perchlorate or calcium perchlorate—dispersed in a polymer matrix. Among different polymer electrolytes, mainly based on poly(ethylene oxide) matrices, ion-conducting membranes can also be obtained by chemically or physically modifying natural polymers and their derivatives, including hydroxyethyl cellulose, starch, chitosan, agar, pectin, gelatin, and DNA.

Gelatin and DNA are natural macromolecules made up of different entities that vary according to the method of extraction, location, and other environmental factors. Gelatin is very interesting because of its biocompatibility, biodegradability, and low production cost. It also has favorable physical and chemical properties, such as low toxicity and the ability to form films and membranes. Moreover, the functional properties of these films can be improved by adding cross-linking agents like formaldehyde, glutaraldehyde, or glioxal.

Figure 1. Gel electrolytes obtained from (a) colorless gelatin-, (b) red gelatin-, and (c) DNA-based membranes.

Over the past few decades, DNA has occupied center stage in biological research. The well-known function of this nucleic-acid macromolecule is to code for proteins that carry the genetic code of life. In the past few years, however, the discovery that DNA can also conduct electrical current has made it a tantalizing candidate for other roles that nature may not have intended. In particular, DNA-based circuits could provide a nanoscale alternative to classical silicon-based electronics, a technology that is widely predicted to be approaching its limits. DNA electronics is a highly interdisciplinary field, merging physics, biology, chemistry, computer science, and engineering to find ways of employing individual DNA molecules to produce a new range of devices that are smaller, faster, and more energy efficient than present semiconductor-based versions.

Recent studies of gelatin- and DNA-based gel electrolytes (see Figure 1) show that these materials have ion-conductivity values for protons and lithium cations comparable to those of semiconductors, yielding \(10^{-5} - 10^{-3}\) S/cm at room temperature, depending on the sample and conducting species. For DNA-based membranes, the ion-conductivity values as a function of temperature increase linearly from \(3.6 \times 10^{-6}\) S/cm at room temperature to \(1.1 \times 10^{-4}\) S/cm at 91°C. For red gelatin-based membranes, the values are \(5.0 \times 10^{-5}\) S/cm at room temperature to \(5.2 \times 10^{-4}\) S/cm at 81°C. Addition of lithium salt to the membrane formulation leads to improvement in ion conductivity by an order of magnitude, to \(2.0 \times 10^{-5}\) S/cm at room temperature.

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room temperature. This enhancement reaches $2.3 \times 10^{-4} \text{S/cm}$ at 81°C for the DNA-based samples, and $2.7 \times 10^{-4} \text{S/cm}$ at room temperature and $2.2 \times 10^{-3} \text{S/cm}$ at 88°C for the red gelatin-based samples. Applying colorless-gelatin electrolytes in electrochromic devices also showed very promising results, changing color from transparent to blue more than 10,000 times.3 These results, combined with good transparency in the visible region of the electromagnetic spectrum and good adhesion to glass and steel, make gelatin and DNA very interesting materials for their targeted applications. These include new optical and electro-optic switches, organic transistors, and optical information-storage materials. Our research on gelatin- and DNA-based gel electrolytes currently focuses on their electrochemical stability. As a next step, we plan to replace water with organic solvents and experiment with using electrolytes in electrochromic devices and solar cells.

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Author Information

Agnieszka Pawlicka and Alessandra Firmino
Departamento de Físico-Química
Instituto de Química São Carlos
Universidade de São Paulo
São Carlos, Brazil
http://www.iqsc.usp.br

Agnieszka Pawlicka graduated from the Chemistry Institute of the University of Technology of Warsaw (Poland) in 1988 and received her PhD in chemistry from the Universidade de São Paulo in 1993. She is a specialist in the chemistry of condensed matter in the areas of solid polymer electrolytes, thin films, electrochromic devices, conducting polymers, and natural polymers.

Alessandra Firmino is a PhD candidate.

James Grote
Air Force Research Laboratory
Materials and Manufacturing Directorate
Wright-Patterson Air Force Base, OH

James Grote is principal electronics research engineer.

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