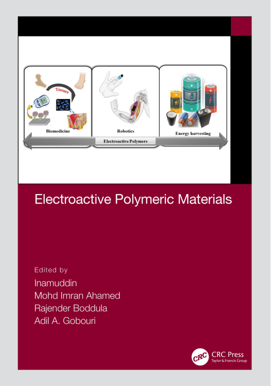

# Electroactive Polymeric Materials

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# Electroactive Polymers for Packaging Technology

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# 18 Electroactive Polymers for Packaging Technology

*Pinku Chandra Nath, Ria Majumdar, Tarun Kanti Bandyopadhyay, Biswanath Bhunia, and Biplab Roy*

## CONTENTS

## 18.1 INTRODUCTION

In this era of emerging technologies, conventional materials (e.g., metals, alloys, and ceramics) have been replaced by polymers, such as homopolymers, copolymers, blends of small molecules, complexes, and composites, which are being used in household goods, aerospace, automobiles, packaging industries, electronics, and medical sciences. These polymeric materials have tremendous advances; therefore, several processing techniques have been developed to date, and are being developed to enable polymer production with tailor-made properties (e.g., physical and mechanical). Theses feature of polymers that allow the invention of new designs with cost-effective and light weights makes them interesting for growing technologies (Guru Nathan *et al.*, 1999). However, unlike inorganic materials, polymers have different attractive properties, for example, they are light weight, easily processed, pliable, and fracture tolerant. These can be configured into various complex shapes and their properties can be tailored into what is required (Bar-Cohen, 2004). Different materials with artificial intelligence and rapid advances (e.g., piezoelectric materials and shape memory materials) can sense changes in the environment, process that information and then respond accordingly (Irinyi, 2000). Polymers that respond to external stimuli, for example, pH, electrical field, light, and magnetic fields by changing their shape or size are active polymers and have been known for several decades (Bar-Cohen, 2004). Therefore, polymers that change shape, or dimensions, or both when exposed to an electric field are electroactive polymers (EAPs) (Carpi and Smela, 2009).

EAPs are materials that have been modified so that they can convert electrical impulses into mechanical movements, which is a principle that enables the production of capacitive sensors, actuators, and generators. Because of their restricted actuation capacity, EAPs initially received less attention. However, in the last two decades, EAPs have emerged that have a significant response

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to electrical stimulation by changing their shape. Several novel mechanisms and devices, such as miniature grippers, robot fish, active diaphragms, loudspeakers, catheter steering elements, and dust wipers have recently established using these materials as actuators. However, actuators for packaging purposes are increasing in current technologies. The benefits from improvements in their actuation strain capacity have attracted many scientists and researchers from various fields. The activation mechanism of polymers that can change their dimension or shape include optical, electrical, magnetic, chemical, and pneumatic. EAP materials provide various advantages, such as light weight, pliable, fracture tolerant, and inexpensive. However, converting EAP materials into an actuator of choice requires a well-established infrastructure and this includes an improvement in the understanding of the basic principles. In addition, electromechanics analytical tools, effective computational chemistry models, material processing techniques, and comprehensive material science are required to improve the understanding. Electrical stimulation causes elastic deformation in polymers and its convenience, practicality, and recent improvement in capacity have made EAP materials one of the most interesting among all the active polymers.

## 18.2 SIGNIFICANCE OF ELECTROACTIVE POLYMERS

EAP materials can be converted into various shapes for engineering purposes; therefore, their properties make them more attractive in a variety of potential applications to overcome growing challenges. Electrical currents cause EAP materials to distort in shape and size, which increases the strain rate by approximately 300% (Bar-Cohen, 2002). Potential applications for EAPs in different fields are power generators, robotics, aerospace, medical, articulation mechanisms, clothing, sensors, and smart structures. The actuator-based EAP materials have some advantages including low actuation voltage, flexible, quick response, and light weight (Rao, 2014).Wang *et al.* (2009) showed that Flemion (an ionic polymer based tactile sensor) that acts as actuators could be applied to produce microelectromechanical systems (MEMS) and smart materials, which had a low actuation voltage and greater strain. Due to the excellent actuation characteristics of EAP materials they are widely used in aerospace applications. In tissue engineering, EAP materials can be utilized as biomaterials to promote proliferation and cellular adhesion in human cells by evading biofilm development through bactericidal effects (Figure 18.1). Wu *et al.* (2018) produced optimal EAPs for applications

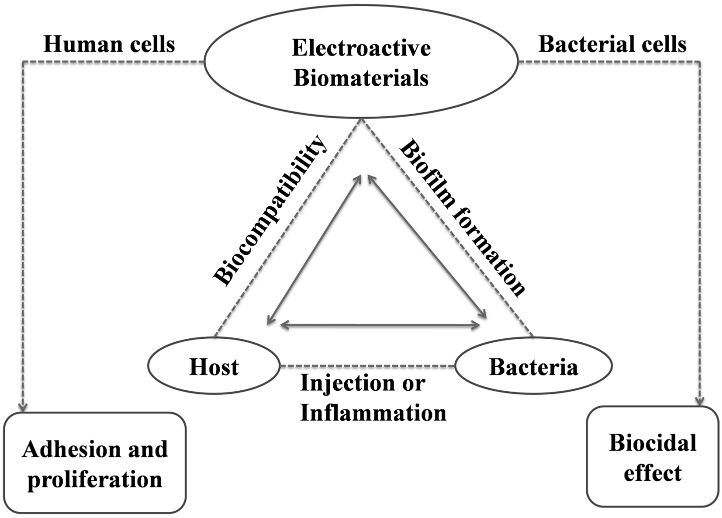

**FIGURE 18.1** Relationship between EAP materials and human and bacterial cells.

**(From Wu and Le Gorrec, 2018. With permission.)**

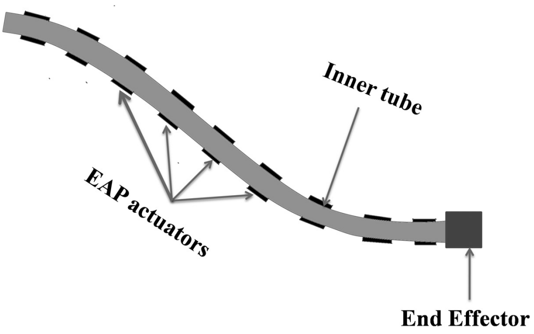

**FIGURE 18.2** EAP-based actuated endoscope.

**(From Wu and Le Gorrec, 2018. With permission.)**

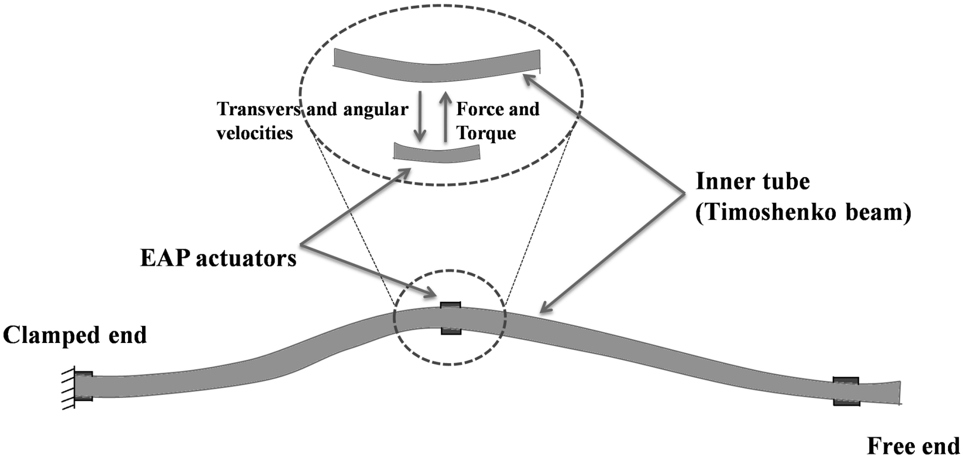

**FIGURE 18.3** Complete simplified actuated endoscope.

**(From Wu and Le Gorrec, 2018. With permission.)**

in medical endoscopes with the help of a Hamiltonian modeling framework. Figure 18.2 shows an EAP-based actuated endoscope where the coating is provided outside the medical endoscope. Figure 18.3 shows a complete medical endoscope where the inner part of the endoscope represents a Timoshenko beam. The left end section of the beam is constant and the right is free. The beam and actuator are interconnected by power conjugated variables. To increase haptic technology, EAP materials have been applied in the automobile sector. This technology provides mechanical feedback when driving on the road. Poncet *et al*. (2016) reported haptic circular buttons that provided vibration sensation, which could be detected by touching them.

## 18.3 CLASSIFICATION OF ELECTROACTIVE POLYMERS

EAPs are mainly divided into ionic and electronic EAPs according to their activation mechanisms (Bar-Cohen, 2004).

### 18.3.1 Ionic Electroactive Polymers

Unlike electronic EAPs, these EAPs are materials that involve in the transportation of ions, and they are composed of an electrolyte along with two electrodes. The activity of ionic EAPs can be achieved by decreasing the voltage to 1 to 2 V. Composites of polymer and metal, carbon nanotubes, gels, and conducting polymers are types of EAPs (De Luca *et al.*, 2013; Shahinpoor *et al.*, 1998). Ionic EAPs have disadvantages, such as their wetness and the electrochemical coupling required for correct maintenance.

### 18.3.2 ELECTRONIC ELECTROACTIVE POLYMERS

Electronic EAPs are materials that have a large mechanical energy density and include piezoelectric (Nalwa, 1995), dielectric elastomers (Carpi *et al.*, 2015; Pelrine *et al.*, 2000), electrostrictive, liquid crystal polymers (Ji, Marshall, and Terentjev, 2012; Lehmann *et al.,* 2001), ferroelectric (Wang, Herbert, and Glass, 1988), and electrostatic polymers. They are driven by Coulomb forces and can be operated in air with no constraints. However, a large activation field (>10 V/μm) is required for this EAP, which is approximately the breakdown level, but it consumes low electrical energy. In addition, dielectric EAPs do not require any power to keep the actuator in place. Dielectric EAPs are polymeric materials that are compressed between two electrodes by electrostatic forces. Dielectric elastomers can withstand extremely high strains, and capacitors change capacitance during an applied voltage where the polymer is allowed to decrease in thickness by expanding its area at its core due to the electrical field.

## 18.4 APPLICATION OF ELECTROACTIVE POLYMERS IN PACKAGING

In the packaging industry, EAP materials have received attention from researchers because of some exceptional advantages that include product protection, lightness, durability, inert atmosphere, and stability. In the food packaging industry, EAP materials have been used for the formation of edible coatings, which is a green and novel packaging application. The coatings used for packaging must have characteristics, such as non-toxicity, non-allergic, and excellent structural stability.

### 18.4.1 LUNCH BOX PACKAGING

In some countries, people use a variety of lunch boxes for convenience. Based on the of huge demand, lunch box packaging is still required due to their variety, high deformability, fragility, physical properties of the food, and various shape variations (Iwamasa and Hirai, 2015). To minimize labor costs, lunchbox packaging automation systems in the food industry are in high demand. Figure 18.4(a) shows a typical lunch box that contains dishes made from polymeric plastic materials and Figure 18.4(b) shows some easily deformable frustum shaped containers (Wang *et al.*, 2017). Lunch box packaging consists of picking, placing, and filling with foodstuffs. In the food packaging

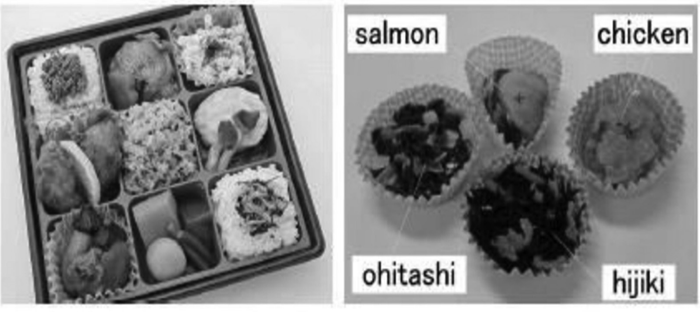

**FIGURE 18.4** Showing: (a) commercial lunch box; and (b) paper containers filled side dishes.

industry, the traditional rigid gripping and vacuum system faces many difficulties to manage the tasks, due to the strong grip food materials can be damaged. Therefore, suction might be used is a flat surface is provided to handle the task. Soft pneumonic robotic grippers have piqued the interest of researchers recently due to their adaptability and flexibility. A four fingered gripper composed of fiber-reinforced rubber has been proposed, which has been experimentally tested for various grasping modes (Suzumori, Iikura, and Tanaka, 1991; Suzumori, Iikura, and Tanaka, 1992). Thermo-formed containers can be formed by heating polymer sheets in a mold at a specific temperature to provide a specific shape. These containers might be used for muffins, cheese, and cookies. Coating paper with EAP materials led to innovative packaging with excellent properties. Coating-based papers have high permeability, good moisture content, fat resistance, and water sensibility. Barrier films or blown films can be manufactured from biodegradable EAP materials by the extrusion of different polymers. In general, for edible film production extrusion, electro spinning process, and compression molding are used (Hernandez-Izquierdo and Krochta, 2008; Mason, 2009).

## 18.5 PROPERTIES OF ELECTROACTIVE POLYMERS FOR PACKAGING APPLICATIONS

### 18.5.1 Properties of Gas Barriers

In the packaging industry, to increase shelf life and the quality of packaging, controlling gas pressure conditions is important. Three gas or a mixture of them are required for packaging: oxygen ($O_2$), nitrogen ($N_2$), and carbon dioxide ($CO_2$) (Shalini and Singh, 2009). To maintain the gas composition inside the packaging materials, the materials require gas barrier properties. The application of multilayers could improve barrier properties. One of the important characteristics of a gas barrier is the permeation capacity. The permeation capacity of EAP materials increases with increasing humidity. In food packaging, the maintenance of $O_2$ and water permeability during shelf life of the food material is an important criterion. In addition, with increasing crystallinity the film barrier properties are improved. According to Bastioli *et al.* (1995),a multilayered film (i.e., metalized) with $N_2$, $CO_2$, and vacuum condition improves product shelflife (Bastioli *et al.*, 1995).

### 18.5.2 Mechanical, chemical, and thermal Properties

The excellent mechanical and thermal properties of the packaging material protect products from mechanical or thermal damage during transportation and storage. Increasing the thermal degradation temperature can improve the materials mechanical and thermal properties. In addition, they determine product suitability in numerous applications. The enhancement of the physical, chemical, and mechanical characteristics of EAPs can be obtained by nano-reinforcement and blending different polymers. To obtain excellent mechanical properties in EAP materials, tensile tests must be characterized, such as tensile strength (MPa), per cent elongation at breakage, yield, and elastic modulus. Buttler *et al.* (1996) proposed barrier and mechanical characteristics of a plasticized edible film. They observed that plasticization concentration increased the per cent elongation by 25%–45% and reduced the tensile strength by 15–30 MPa. To understand the acid characteristics of packaging materials the performance and suitability of the packaging materials must be assessed over time. Polymer absorption by chemical compounds might influence the mechanical properties of the polymer. The chemical resistance of polymer is analyzed by submerging samples in an acid (e.g., weak or strong) solution at different temperatures, such as ambient temperature (23°C), -18°C, -23°C, and -29°C.

### 18.5.3 Biodegradability

Biodegradability refers to materials that can be split into small compounds via the action of fungi and bacteria (Ghalem and Mohamed, 2008). Biodegradation depends on various environmental parameters including pH, moisture, temperature, and nutrients. Biodegradation occurs in two stages: (1) defragmentation (e.g., by microbial enzymes, moisture, and heat); and (2) biodegradation (e.g., conversion of larger molecules into small compounds by natural acids and enzymes). In biodegradation, after conversion of the molecules into suitable shape, the organism's cell wall absorbs the substances metabolized for energy. In general, polymer degradation occurs due to microbial or chemical action and via photodegradation.

### 18.5.4 MOISTURE BARRIER PROPERTIES

A moisture barrier protect the materials from the entry of undesired vapors, and is calculated by water vapor transmission rate (Alavi *et al.*, 2015). Packaging materials that contain undesired vapors that results in recovering moisture in dry foods. This moisture can be removed by forming moisture resistant films that are produced by reinforcement with natural fibers and blending and coating with water-resistant materials. The barrier properties rely on the material's morphological properties, such as chain configuration and crystallinity. Shelf life can be increased by increasing the moisture barrier in food packaging. Morillon *et al.* (2002) reported moisture sensitivity in protein films and observed that a moisture barrier was increased by blending with other bio-based materials. Baastioli *et al.* (1995) reported a solvent-based dispersion coating on a biopolymer layer and achieved excellent properties for the moisture barrier. In packaging applications, $O_2$ and water vapor are two important permeants. The $O_2$ barrier is evaluated by the oxygen permeability coefficient (OPC), which shows the quantity of $O_2$ that permeates per unit time and area. If the packaging film has low OPC, $O_2$ pressure inside the packaging decreases to a limited oxidation condition that improves product shelf life. The water vapor permeability coefficient is the water vapor permeation per unit time and area and is used to determine the water vapor barrier. For fresh produce, this is necessary to evade dehydration and for bakery products, water permeation should be avoided.

## 18.6 CONCLUSION

This chapter discussed the basic information on EAP materials, their importance over other materials that enables the development of advanced and cost-effective new devices, and thier significant applications in packaging materials. Although EAP materials are used in various fields, they have achieved received interest as packaging materials, because of their unique properties. EAPs have emerged as one of the most attractive materials to researchers and scientists, because advanced and cost-effective new models can be developed by changing their shape to the electric stimulation. In addition, they can change rapidly with small variations in the environment, which makes them attractive in modern packaging technology.

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