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Opinion

Dielectric Hydrogels: Materials for Sustainable Energy Storage

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Abstract

In recent years, dielectric hydrogels were found to take an enabling role in important fields of polymer chemistry and material science. Tailored dielectric hydrogels combine the unique dielectric properties with the flexibility and properties of macromolecular architectures, giving rise to a new family of functional polymers that opens new areas of applications such as stretchable electronics. In this short colloquy, an overview of dielectric hydrogels has been provided. It is envisioned that these materials will impact a range of sensory applications in material science field.

Opinion

The discovery, development and deployment of new polymeric materials given a new dimension to the present era, this young branch of chemistry, has been the subject of great development both as a basic and applied science provides new business opportunities as well as to drive advances in high value application ranging from microelectronics to medicine [1,2]. In the first instance, polymers are generally known for their insulating property because of the covalent bonds present in saturated carbon compounds. Since desirable properties can be conveniently attained by tailoring the polymer structure and also by incorporating additives; scientists have been enthusiastic to explore the possibility of transforming insulating polymers into conducting or semiconducting materials predicting such special characteristics like low density, ease of fabrication, flexibility of design, low energy and labor requirements for fabrication and processing. Later the possibility of combining new chemical functions in a backbone opened new fields of applications for macromolecules. So structures with specific uses were developed creating new interfaces with technological fields [3,4].

In particular, the development of polymers for electronics is still an open field where polymers are used not only as insulators, but where the electronic properties of these featured macromolecules can be tailored for specific applications [5]. The great effort that is still pursued in this field is responsible for both the optimization of new polymeric structures and for the upsurge of developing new and more efficient synthetic protocols. The fast development of this branch of polymer science has stimulated the interest of the industrial world and nowadays there are several small, medium and big enterprises, both in the chemistry area and in the microelectronics sector, developing high frequency power devices, high frequency small signal amplifiers, in many discrete appliances and actuators [6,7].

Hydrogel is a cross linked three-dimensional (3D) network structure composed of hydrophilic polymers that can hold the large amount of water inside the matrix. Due to their momentous water content, hydrogels possesses degree of flexibility similar to natural tissues. The network hydrophilicity of the hydrogels is due to the presence of hydrophilic moieties such as $–NH_2$, $–COOH$, $–SO_3H$, $–PO_3H$ $–OH$, $–CONH_2$, and –CONH–. Hydrogels are ubiquitous in many industrial applications, such as drug delivery, tissue scaffolds, microfluidics, and fuel cell membranes, where controlling selective transport is critical to the performance of the device [8]. Current trends in microelectronic packaging have shown a need for developing advanced dielectric materials for realization of high performance interconnects of electronic devices. Much of the research has focused on developing complex micro patterns switched by hydrogel-actuated nanostructures to achieve higher system performance in high speed digital applications.

Dielectrics are materials that do not conduct electricity, essentially functioning as insulators, but whose electrical performance must meet more stringent requirements. When exposed to an electric field, the electric charges in a dielectric material, including permanent and induced electric dipoles, can be moved, thus polarizing the material. Although the equilibrium polarization remains a material constant for a given electrical field, it is the dielectric constant, ε, or also symbolized by *k*, that is used to characterize the dielectric properties of the dielectric. In an alternating (AC) field, the dielectric constant is a complex quantity, ε*, and is the combination of a real component, called the relative permittivity or dielectric constant, ε', and an imaginary component, called the dielectric loss or dissipation factor, ε''. This form, also called the complex dielectric permittivity, is defined by the formula (1):

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1)$$

Dielectric constant (ε') is a critical electrical parameter for a microelectronic polymer dielectric. The magnitude of ε' depends on the amount of mobile (polarizable) electrical charges and the degree of mobility of these charges in the material. Because the charge mobility depends on temperature, ε' is temperature dependent, and since polarization of the material requires a finite amount of time, the frequency of the electric field also influences the measured dielectric constant. The lower the dielectric constant, the faster the signal propagation velocity, as given by the Equation (2):

$$V_p = c/(\sqrt{\varepsilon'}) \quad (2)$$

Where V_p is the velocity of propagation and c is the speed of light. A lower dielectric constant allows for wider signal traces and a decrease in the dielectric thickness. It also allows a designer to maintain the same characteristic impedance while lowering the line resistance and crosstalk [9].

Inorganic materials/ceramics show high dielectric constant than polymers. It possesses ions and polar functional groups intrinsically and contributes to their high dielectric constant. Both polymer dielectrics with low and high dielectric constant are essential in electronic industries. Low dielectric constant is required basically as insulators and preferably useful in designing integrated circuits (IC). High ε' materials are used as polarizable media for capacitors, and in apparatus such as rectifiers and semiconductor devices, piezoelectric transducers, dielectric amplifiers, and memory elements [10].

Recently, Gao et al. [11] has designed pH-responsive dielectric hydrogels with improved mechanical and dielectric properties. The properties and classical applications of polyelectrolytes are being outspreading in the last few years by the introduction of dielectric materials into the polymer matrix. These new materials are being developed due to the scientific and technological interest in the field of stretchable electronics [12,13]. The field of dielectric hydrogels has expanded over the past few decades and has become fundamental to the science of polymer technology, the intriguing properties and the wide range technological interests has been an ever increasing stimulus to fully focus on specialized applications [14] and thus promising candidates for energy storage applications.

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