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Letter

Experimental investigation on electromechanical deformation of dielectric elastomers under different temperatures

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ABSTRACT

Under an applied voltage, dielectric elastomers (DEs) produce an actuation strain that is nonlinear, partly because of the material properties. In this study, an experimental characterization is conducted to evaluate how the ambient temperature and pre-stretch affected the actuation performance. For DEs with a pre-stretch of 2×2, an increase of temperature from $-10°$ to $80°$ results in a variation in the actuation strain of more than 1700%. Low pre-stretched DEs are more susceptible to temperature change; while highly pre-stretched DEs are relatively insensitive to temperature, because in this case the energy conversion was dominated by mechanical stretching, rather than thermal conduction, during the actuation.

Dielectric elastomers (DEs) are soft active materials that exhibit a large strain response when they are subjected to an electrical excitation [1]. Because these characteristics resemble the properties of biological muscles, DEs have been investigated for biomimetic applications such as soft robots, artificial skin, tunable lenses, refreshable Braille displays, and nanostructured polymer systems in recent years [2–5].

Dielectric elastomers display a high nonlinearity in their actuation, which is partly attributed to the material properties. Both the mechanical and the dielectric properties are sensitive to changes in the temperature and the degree of pre-stretch applied. Moreover, Liu et al. [6] theoretically predicted that as the temperature increases, the stretch of the dielectric elastomer is strengthened. An acrylic VHB polymer from 3M company is the most widely employed dielectric elastomer, but it shows strong stiffening in elasticity at large mechanical stretches [7]. Michel and Vu-Conga et al. [8,9] showed that the elastic modulus of DEs decreased by over two orders of magnitude when the temperature was increased from −50°C to 75°C. The dielectric constant is also sensitive to changes in the temperature, as shown in a series of experiments reported in the literature [10–12]. For instance, when the area expanded by four times, the dielectric constant dropped by 50%. Although the nonlinear properties have been reported separately, the above experiment focused on the characterization of individual factors, rather than considering the overall actuation performance during electromechanical coupling. The relationship between the temperature and the pre-stretch and their combined influence on the actuation remain unclear. We therefore present here a series of experiments on dielectric elastomers, measuring the voltage-actuation strain when the material is under both thermal and mechanical loading.

Fig. 1 shows the experimental setup. VHB 4910 film (3M company) with an original thickness of 1 mm was selected as the dielectric elastomer. The film was stretched to prescribed levels, while being fixed to a rigid frame to maintain the mechanical strain load. Carbon grease (No. 846, MG Chemicals) was then applied to the surface of the film, forming a circular pattern for actuation, as shown in Fig. 1(a). The circular configuration was characterized by its simpler structure and its response, which was tuned by varying the pre-stretch and the ratio of the electrode area to the passive area. These characteristics helped to reflect the effects of changing the temperature and the pre-stretch on the actuation performance more directly and conveniently. A lightweight copper marker was attached at the edge of the electrode area, and the displacement of

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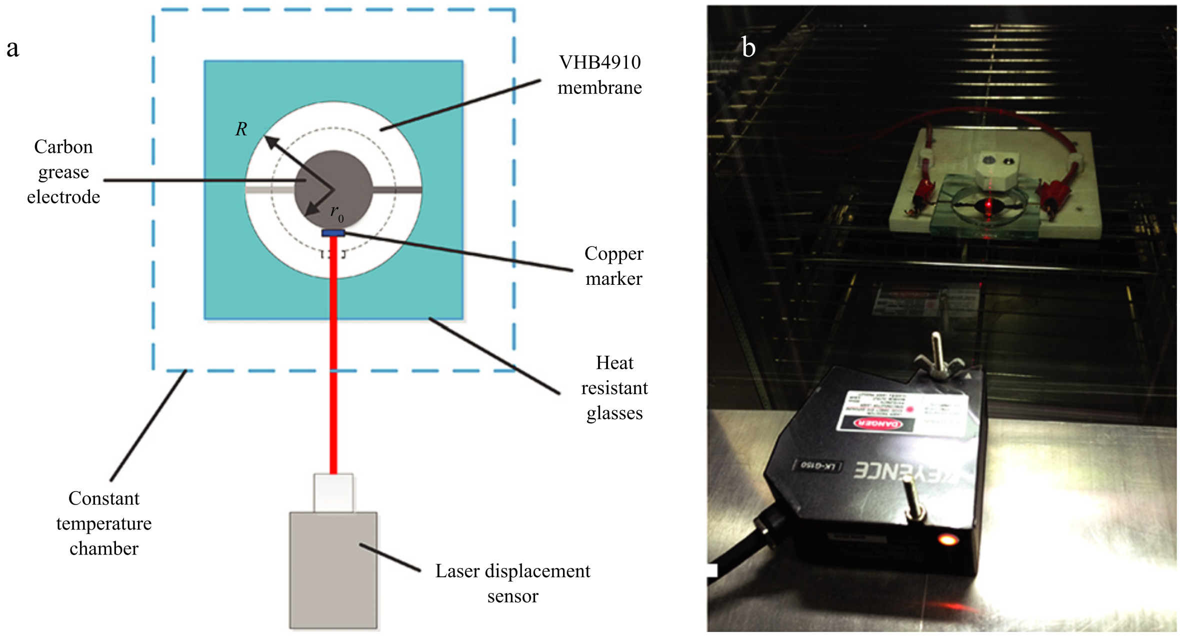

Fig. 1. Experimental setup. (a) Schematic sketch of the system, and (b) example of a DE actuator inside a heat chamber with a laser sensor.

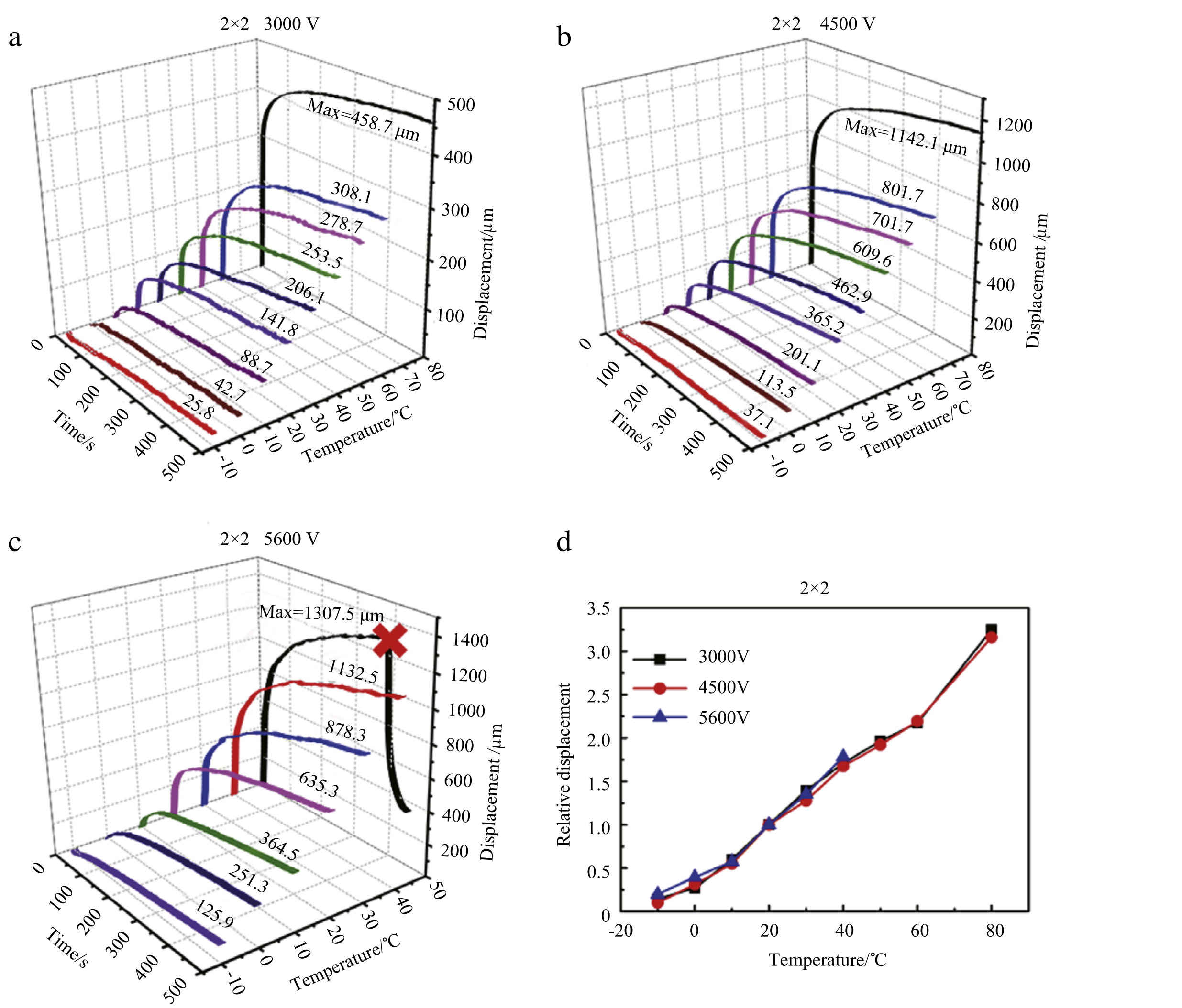

Fig. 2. (Color online) Responses of the DE actuation displacement, with an equal biaxial area pre-stretch of 2×2 at three different voltages of (a) 3000 V, (b) 4500 V, and (c) 5600 V. The temperature range was −10°C to 80°C. The red cross shown in plot (c) denotes the electric breakdown. (d) Relative displacement vs. temperature.