

THEORY AND EXPERIMENTS OF DIELECTRIC ELASTOMERS

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Summary In response to a stimulus, a soft material deforms, and the deformation provides a function. We call such a material a soft active material (SAM). This review focuses on one class of soft active materials: dielectric elastomers. When a membrane of a dielectric elastomer is subject to a voltage through its thickness, the membrane reduces thickness and expands area, possibly straining over 100%. The dielectric elastomers are being developed as transducers for broad applications, including soft robots, adaptive optics, Braille displays, and electric generators. This paper reviews the theory of dielectric elastomers, developed within continuum mechanics and thermodynamics, and motivated by molecular pictures and empirical observations. The theory couples large deformation and electric potential, and describes nonlinear and nonequilibrium behaviour, such as electromechanical instability and viscoelasticity. The theory enables the finite element method to simulate transducers of realistic configurations, predicts the efficiency of electromechanical energy conversion, and suggests alternative routes to achieve giant voltage-induced deformation. It is hoped that the theory will aid in the creation of materials and devices.

GIANT VOLTAGE-INDUCED DEFORMATION

I have recently published a review article on the theory of dielectric elastomers [1]. The theory has been applied to examine how to achieve giant voltage-actuated strains [2-4]. The deformation of a dielectric induced by voltage is limited by electrical breakdown if the dielectric is stiff, and by electromechanical instability if the dielectric is compliant. The interplay of the two modes of instability is analyzed for a dielectric elastomer, which is compliant at a small stretch, but stiffens steeply. The theory is illustrated with recent experiments of interpenetrating networks, and with a model of swollen elastomers. The theory predicts that, for an elastomer with a stress-stretch curve of a desirable form, the voltage can induce giant deformation.

ENERGY HARVESTING

The theory has also been used to examine and how much energy can be converted by using dielectric elastomer generators [5,6]. We model a generator as a system of two degrees of freedom, represented on either the stress-stretch plane or the voltage-charge plane. A point in such a plane represents a state of the generator, a curve represents a path of operation, a contour represents a cycle of operation, and the area enclosed by the contour represents the energy of conversion per cycle. Each mechanism of failure is represented by a curve in the plane. The curves of all the known mechanics of failure enclose the region of allowable states. The area of this region defines the maximum energy of conversion. This study includes the following mechanisms of failure: material rupture, loss of tension, electrical breakdown, and electromechanical instability. It is found that natural rubber outperforms VHB elastomer as a generator at strains less than 15%. Furthermore, by varying material parameters, energy of conversion can be increased above 1.0 J/g.

References

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