

Mechanical instabilities in layered soft dielectric elastomers

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Abstract

Smart soft devices rely on reversible, electrically driven shape changes, but their design is often limited by the onset and evolution of nonlinear instabilities. In this contribution, we develop a unified electro-elastic framework to predict and control morphological transitions in dielectric elastomer (DE) systems, combining analytical stability tools with fully nonlinear finite-element simulations. First, we study layered DE balloons subjected to inner pressure and a radial voltage, and characterize the transitions between spherically symmetric deformation, buckling, necking, and snap-through. Second, we investigate voltage-controlled wrinkling in a dielectric film bonded to a hyperelastic substrate, clarifying how electric fields and pre-stretch cooperate to trigger on-demand surface patterning. Using the Stroh formalism and the surface impedance method, we derive exact and sixth-order approximate bifurcation equations yielding critical stretch, critical voltage, and critical wavenumber. We identify regimes in which mechanical wrinkling precedes dielectric failure and establish thresholds in shear modulus ratio and pre-stretch that allow wrinkles to be activated with relatively small voltages. Nonlinear finite-element simulations (FEniCS) validate the analytical predictions and provide a post-buckling analysis. Together, these results offer a quantitative, design-oriented route to electrically programmable shape for soft robotics, adaptive actuators, flexible electronics, and smart surfaces.

Keywords:

Electro-elasticity nonlinear mechanics mechanical instability finite element analysis