Electromechanical Buckling and Postbuckling of Periodic Patterns of Stiff Film on a Compliant Dielectric Substrate - Analytical and Numerical Analyses

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KEYWORDS: *Electromechanical Buckling, Dielectric Compliant Substrate, Wrinkling, Periodic Patterns.*

The work presents and discusses analytical and numerical solutions for the electromechanical buckling and postbuckling states of a planar stiff film bonded to a compliant dielectric substrate. The thin metal film forms an upper electrode. The compliant substrate is attached to a bottom rigid, and fixed electrode. The film is simultaneously subjected to in-plane compression stresses and to out-of-plane electrostatic attraction forces. The electrostatic forces can be induced by applying a voltage difference between the upper elastic electrode and the lower fixed electrode. Electromechanical buckling instability stems from the coupling of mechanical buckling instability and electromechanical pull-in instability. As revealed, such instability coupling can be employed to instigate mechanical buckling [1]. This work establishes an analytical approach to study the electromechanical critical and post-buckling behavior of one-dimensional square checkerboard, hexagonal, and herringbone periodic buckling patterns, illustrated in Fig. 1.

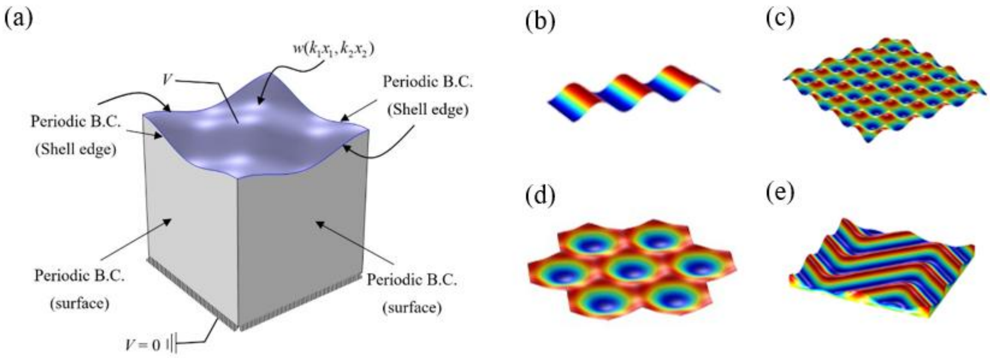

Figure 1. (a) One cell of a system of a film electrode on a compliant dielectric substrate. (b) – (e), 1D, square checkerboard, hexagonal, and herringbone periodic patterns.

Unlike previous works, the electrostatic attraction force and energy contributions are derived from the analytical solution of the electric potential function. A modified version of von-Karman plate equations is formulated and used along with the upper-bound energy method to derive analytical solutions for the critical and post-electromechanical buckling states of the considered patterns. The analytical, critical, and postbuckling solutions, as well as the energy state of periodic patterns, are validated through a rigorous finite element analysis conducted in COMSOL Multiphysics software. It has been revealed that the buckling stress and periodicity wavelength strongly depend on the applied voltage. The ability to determine the buckling stress by varying the applied voltage enhances the potential for microsystem applications.

[1] Abu-Salih S., Journal of the Mechanics and Physics of Solids 197 (106062), 2025. https://doi.org/10.1016/j.jmps.2025.106062