

Finite Element Analysis of Thermo-Mechanically Driven Piezoelectric Power Generation in piezoelectric polymer/LCE Architecture

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Piezoelectric nanogenerators (PENGs) convert mechanical deformation into electrical signals and have been widely investigated for self-powered systems [1]. Most designs rely on externally applied mechanical loading; however, the integration of stimuli-responsive soft materials enables deformation driven directly by environmental changes. Liquid crystal elastomers (LCEs), which exhibit reversible anisotropic thermomechanical actuation associated with the nematic–isotropic transition [2,3], provide a suitable platform for thermally induced piezoelectric generation.

Here, we investigate a multilayer laminated structure composed of alternating poly(vinylidene fluoride-trifluoroethylene) (P(VDF-TrFE)) and LCE layers. Temperature variation induces orientation-dependent contraction or expansion of the LCE, leading to curvature mismatch within the multilayer stack. The resulting bending–release deformation generates mechanical strain in the piezoelectric layers and produces electrical potential via the piezoelectric effect. The structure therefore operates as a thermally driven bending-type piezoelectric generator.

A finite element method (FEM) framework is employed to describe the coupled thermo-mechanical and electromechanical response [4]. The model incorporates temperature-dependent elastic properties of the LCE, anisotropic thermal strain along the liquid crystal director, and linear stress–charge form piezoelectric constitutive relations for P(VDF-TrFE) [5,6]. Parametric analyses are conducted by varying the layer thickness ratio and total number of layers to evaluate their influence on curvature evolution and voltage output.

The simulations indicate that the electromechanical response is sensitive to the device architecture. In particular, the overall performance depends on structural parameters such as layer thickness and the number of stacked layers, suggesting that structural optimization is required to achieve favorable output characteristics. These results clarify the structure–property relationships governing thermally induced electromechanical behavior under cyclic heating and cooling. The proposed multilayer configuration provides a quantitative framework for integrating thermo-responsive actuation with piezoelectric functionality in coupled material systems.

References

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