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Dynamic flexoelectric effect on piezoelectric nanostructures

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Abstract

Flexoelectricity, which represents the spontaneous electric polarization induced by the strain gradient, is a universal electromechanical coupling effect regardless of symmetry in all dielectric material. In solid dielectric material, the contribution from flexoelectricity can be due to four related phenomena: static and dynamic bulk flexoelectricity, surface flexoelectricity and surface piezoelectricity. While the surface flexoelectric effect can be negligible, the magnitude of the remaining three phenomena are comparable. Presently, the role of the static bulk flexoelectric and surface piezoelectric effects in the energy harvesters has been intensively studied, the contribution from dynamic flexoelectric effect remains unclear. In this work, based on the conventional beam theory, equations of motion considering dynamic flexoelectric effect are investigated. Consequently, the free vibration of the simply supported beam is studied in order to examine the influence of the dynamic flexoelectricity on natural frequency. From the numerical studies, it is found that dynamic flexoelectric effect is more influential on thick beam model and higher vibration modes. In addition, the results show that the relation between the static and dynamic flexoelectric coefficients can also alter the free vibration response.

Keywords: Flexoelectricity, Dynamic flexoelectric, Beam model, Free vibration

1 Introduction

Coupled electromechanical phenomena plays an essential role in many engineering applications, such as sensors, actuators and energy harvesters. These electronic devices have been following the miniaturization trend to micro/nano size such that the required power is very low. Most of these micro/nano structures are based on piezoelectric effect that relates mechanical strain and electric field for non-centrosymmetric material. Flexoelectricity, on the other hand, is a more universal phenomenon (i.e. regardless of symmetry of dielectric material) and represents the spontaneous electric polarization induced by the strain gradient. Recent studies have shown the enhancement from flexoelectricity to electromechanical coupling effect and can be a substitution in case of absence of piezoelectricity in nanostructures. The strong size-dependence due to strain gradient, have made flexoelectricity an attractive research in the field of nano-sized electromechanical structures. For a broader picture of flexoelectricity, the readers are referred to the review articles [1, 2, 3, 4] and references therein.

In the continuum theory context, Majdoub et al. [5, 6] showed the enhancement from flexoelectricity in nano-piezoelectric cantilever beam made of Barium Titanate ($BaTiO_3$). The role of flexoelectricity in nano-piezoelectric beam has been studied in more details in the work of Yan and Jiang [7, 8], in which static bending in clamped-clamped and simply supported beams and their free vibration behaviour were investigated. The authors also summarized the progress of size-dependent piezoelectric nanostructures in [9]. Similar work can also be found in [10]. The surface effects (surface elasticity and piezoelectricity) were included to analyze static and vibration behavior of piezoelectric nanostructures based on beam theory in the work of Liang et al. [11, 12]. It is also worthy to mention the work on variational principles framework for flexoelectricity with surface effects for elastic dielectrics by Shen and Hu [13]. More recently, non-local elasticity is incorporated with flexoelectricity in beam model in [14, 15, 16, 17, 18]. As for numerical analysis of energy harvester, some of us have performed topology optimization for nanostructures considering piezoelectric/flexoelectric effect [19, 20].

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