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Nano-scale energy harvester of piezoelectric/piezomagnetic structures with torsional mode

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ABSTRACT

This work presents a nano-scale cylindrical shell serving as an energy harvester with piezoelectric/piezomagnetic materials. Based on the torsional mode, the surface effects on the properties of the energy harvester are investigated. The results show that the capability of the energy harvester can be enlarged by adjusting the surface material constants. The power density will grow with the increasing of the residual surface stress. Moreover, the performance of the energy harvester can be improved by reducing the total height of the cylindrical shell. The larger height ratio of the piezoelectric to piezomagnetic materials will also lead to greater power density. This paper presents that the energy harvester can be made of nano-scale composite structures, which would be helpful for its application to nano technology.

1. Introduction

During the recent years, self-powered and batteryless sensors have attracted a lot of attention and resulted in extensive researches of energy harvesters [1–5]. The piezoelectric energy harvester is one of the most common and popular harvesters, which can convert the mechanical energy into the electrical power [6–11]. Researches in such area involve further understanding of the basic vibration characteristics for the piezoelectric structures and materials. Therefore, it shows a broad way of providing power for small electronic components and new devices of energy systems.

Superior to the single piezoelectric phase, piezoelectric/piezomagnetic composite materials refer to a class of materials exhibiting the coupling among the magnetic, electric and mechanical fields. Because of their remarkable magnetoelectric coupling effect, piezoelectric/piezomagnetic materials have been widely used in electronics industry. The technical applications include waveguides, sensors, phase invertors, transducers, etc. Therefore, the exploration of the piezoelectric/piezomagnetic structures to energy harvesters is a new but interesting research topic [12,13].

With the fast development of new technology, elements and structures at the nano scale are widely used in electromechanical systems, bioengineering, optical devices, etc [14–18]. In order to achieve the various modern technological advances, people require the mechanical and physical characteristics of the nano-scale structures and systems. The size effects often become prominent when the structural size is on the order of the nanometer [19,20], however, classical elasticity theory cannot account for the intrinsic size dependence. Therefore, the surface effects on the mechanical characteristics play an important role and have received a lot of attention on both elastic [21–24] and piezoelectric structures [25–28].

Accordingly, researchers have made efforts to provide effective and lasting energy for the nano electric devices. The nano-scale energy harvesters are the most promising candidates to be applied on these nano structures. Wang et al. accomplished

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a nano-generating technology by means of piezoelectric zinc oxide nanowire arrays, which could convert the mechanical energy into the electric power [29]. Later, Fan et al. invented a triboelectric nanogenerator to collect electricity from mechanical vibration, which with high energy conversion efficiency and low production cost [30]. Fuh et al. proposed a nano/micro fiber based energy harvester experimentally, from which they could collect all-direction flexible deformations [31]. Bhaskar et al. made up a nano-scale layered flexoelectric cantilever beam as an energy harvester [32]. All of their works have beneficial influences on the development of the application for the energy harvesters at nano scale.

Moreover, kinds of energy harvesters with both piezoelectric and piezomagnetic phases can provide another way for the design and analysis of energy devices. Energy harvesters at nano scale can also have various applications which can meet the demand of the modern technology. According to the previous discussion, this work presents a model of the piezoelectric/piezomagnetic energy harvester at nano scale. In order to describe the characteristics of the nano-scale energy harvester, the surface effects as well as the coupling properties between the piezoelectric and piezomagnetic components are considered.

2. Governing equations

A nano-scale energy harvester with the cylindrical shell is illustrated in Fig. 1 and z-axis is the poling direction. Such system can convert the input magnetic energy from the piezomagnetic part into the output electric energy through the piezoelectric component. The materials parameters of the piezoelectric and piezomagnetic sections are denoted by the superscripts “e” and “m”. The heights of piezomagnetic and piezoelectric parts are a and b. For the cylindrical shell, the radius, thickness and total height are r, t and h. There are two electrodes installed at the top and bottom of the piezoelectric part, respectively. The impedance of the load circuit is Z, which is connected to the two electrodes. The surfaces and the interface of the piezoelectric and piezomagnetic materials are considered as thin membranes so that their thicknesses are not considered.

For the piezoelectric and piezomagnetic materials, the governing equations can be expressed as the following forms:

$$c_{44}^{\mathrm{e}}\frac{\partial^2 u_\theta^{\mathrm{e}}}{\partial z^2}+e_{15}\frac{\partial^2\phi}{\partial z^2}+\omega^2\rho^{\mathrm{e}}u_\theta^{\mathrm{e}}=0 \tag{1a}$$

$$e_{15}\frac{\partial^2 u_\theta^{\mathrm{e}}}{\partial z^2}-\varepsilon_{11}\frac{\partial^2\phi}{\partial z^2}=0 \tag{1b}$$

$$c_{44}^{\mathrm{m}}\frac{\partial^2 u_\theta^{\mathrm{m}}}{\partial z^2}+h_{15}\frac{\partial^2\psi}{\partial z^2}+\omega^2\rho^{\mathrm{m}}u_\theta^{\mathrm{m}}=0 \tag{2a}$$

$$h_{15}\frac{\partial^2 u_\theta^{\mathrm{m}}}{\partial z^2}-\chi_{11}\frac{\partial^2\psi}{\partial z^2}=0 \tag{2b}$$

where ω is the circular frequency, ρ^{e} and ρ^{m} are the mass densities of the piezoelectric and piezomagnetic materials, ϕ and ψ are the electric potential and magnetic potential, u_θ^{e} and u_θ^{m} are the elastic displacements, c_{44}^{e}, e_{15} and ε_{11} are the elastic, piezoelectric and dielectric constants for the piezoelectric materials, c_{44}^{m}, h_{15} and χ_{11} are the elastic, piezomagnetic constants and magnetic permeability for the piezomagnetic materials.

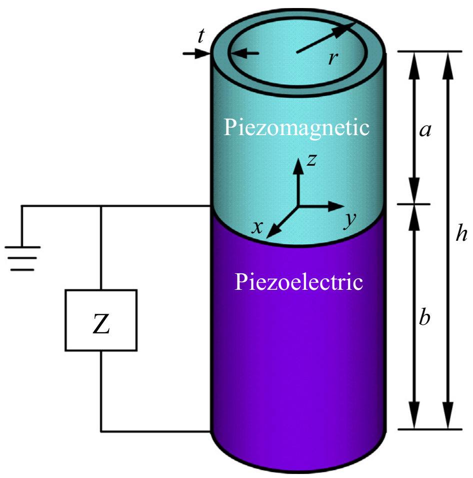

Fig. 1. Structural model for a nano piezoelectric/piezomagnetic cylindrical shell as an energy harvester.