Modeling and Characterization of Piezoelectric Mems Energy Harvester

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ABSTRACT

This paper presents the modeling, characterization of a piezoelectric microelectromechanical systems (MEMS) energy harvester using a d33 piezoelectric mode. A analytical modeling for the d33-mode device were first performed to estimate the output voltage as a function of the material parameters and device geometry. A Zno layer was newly applied as an interlayer between the PZT and silicon dioxide films to improve the piezoelectric property. The cantilever PZT film with an interdigital shaped electrode exhibited a polarization of 3.25e-15C/m^2, a relative dielectric constant of 1125.1, and a d33 piezoelectric constant of 50 pC/N. The simulated energy-harvesting device generated an electrical voltage of 0.3453V for a force 45e-6 of from a vibration. The corresponding electric field and polarization was produced.

KEYWORDS: *energy harvesting, interdigital electrodes, lead zirconate titanate (PZT) , microelectromechanical systems (MEMS), piezoelectric effect.*

I. INTRODUCTION

IN olden days power sources such as electrochemical batterieswhich are used when used in the lowpower- consuming wireless remote sensor systems currently employed for intelligent buildings and environmental monitoring, have some drawbacks such as their environmental pollution, large maintenance requirements, limited storage capacity, and limited lifetime. Now a days, the power consumption of tens to hundreds of microwatts is sufficient for wireless sensor node applications by the rapid development of low power ICs.

Three types of transduction methods that can be used for ambient vibration energy harvesters, namely electrostatic, electromagnetic, and piezoelectric. In these methods, piezoelectric transducers have received much attention because of their simple configuration and high conversion efficiency. Energy harvesters were also designed to operate in the *d*31 piezoelectric mode. In a previous micromachined energy harvester operating in the *d*31 mode which was structured with a parallel-plated capacitor, the output voltage was limited due to its large capacitance. The *d*33 piezoelectric mode, which was configured by an interdigital shaped electrode, was effective in generating a larger output voltage than the *d*31 mode, because it exhibited a much smaller capacitance and the output voltage could be easily controlled by adjusting its electrode gap. In addition, its piezoelectric constant was also much higher than that of the harvester operating in the *d*31 mode. The piezoelectric effect converts mechanical strain into electric current or voltage. This strain can come from many different sources. Human motion, low-frequency seismic vibrations, and acoustic noise are everyday examples. Most piezoelectric electricity sources produce power on the order of milliwatts, too small for system application, but enough for hand-held devices. Piezoelectric materials are permanently polarized crystalline materials. If the dimensions are changed as a result of mechanical force, electric charges proportional to the imposed force are accumulated on the surface up on which the force is imposed. This phenomenon is known as piezoelectricity. This property is exploited to measure many physical parameters such as force, pressure, strain, torque, acceleration, sound and vibration. Piezoelectricity is the combined effect of the electrical behavior of the material

$$D=\varepsilon E$$

where D is the electric charge density displacement (electric displacement), ε is permittivity and E is electric field strength. According to Hooks law

$$S=sT$$

These may be combined into so-called *coupled equations*, of which the strain-charge form is:

$$\{S\} = \left[s^E\right]\{T\} + [d]\{E\}$$
$$\{D\} = [d^t]\{T\} + \left[\varepsilon^T\right]\{E\}$$

where [d] is the matrix for the direct piezoelectric effect and $[d^t]$is the matrix for the converse piezoelectric effect. The superscript *E* indicates a zero, or constant, electric field; the superscript *T* indicates a zero, or constant, stress field; and the superscript *t* stands for transposition of a matrix.In this paper, the modeling of a silicon bulk micromachined energy harvester operating in the *d*33 piezoelectric mode were performed. In this model a single cantilever structure with a silicon inertial mass for scavenging low vibrations with frequencies of several hundreds of hertz. The maximum output voltage, were measured.

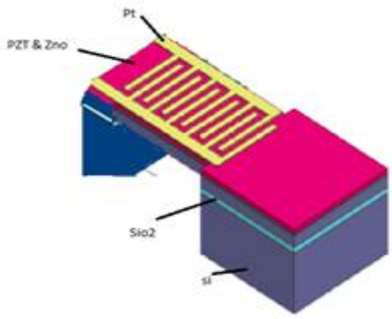

Fig. 1. Schematic drawing of the proposed energy harvester

II. MODELING

Fig. 1 shows the microelectromechanical systems (MEMS) energy-harvesting cantilever device operating in the *d*33 mode for low-frequency vibration conversion. It consists of a single cantilever structure, which is composed of a supporting silicon membrane, a piezoelectric layer, and interdigital shaped electrodes. The proof mass, which is made of silicon, is built at the free end of the cantilever to adjust the resonant frequency and reduce the spring constant.

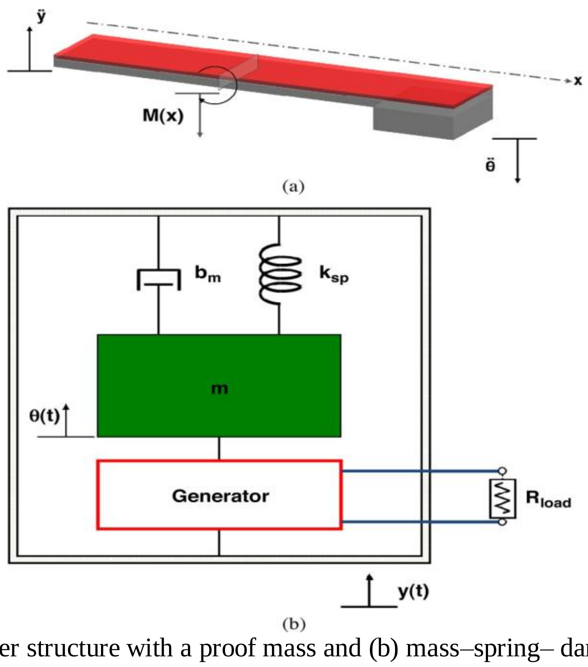

Fig. 2. (a) Single cantilever structure with a proof mass and (b) mass–spring– damper system model of the proposed piezoelectric MEMS energy harvester.

Fig. 2 (a) shows the single cantilever structure of energy harvesting. The vibration of total system is coupled to generator by means of the inertia of mass. This mass (*m*) is modeled as being suspended by a spring with spring constant (*k*), while its motion is damped by a parasitic damping (*bm*). This mass also damped by the generator (*Pg*). The displacement of total mass is $\theta(t)$ and the displacement of this system is represented by $y(t)$. This vibration energy harvester can be express by following equation.

$$m\ddot{y}=m\ddot{\theta}+ bm\dot{\theta}+k\theta+ Pg$$

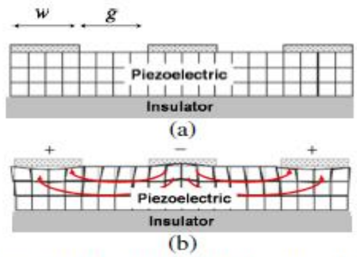

Fig. 3 Conceptual description of d_{33} piezoelectric mode operation on PZT thin film substrate.

The d33 piezoelectric mode in Fig. 3 is more eligible for energy harvesting of low level ambient vibration because d33 mode can generate larger voltage than d31mode with less displacement of cantilever due to followings.Firstly, the stress-strain distribution between electrodes of d33 piezoelectric mode is constant. It's assumed that the thickness of piezoelectric layer is much thinner than silicon membrane. The stress on piezoelectric layer can be expressed as

$$\sigma_{xx} = \frac{M(x)h}{I}$$

where, *l* is the length of the silicon membrane, *x* is the distance from fixed area of the beam, *M(x)* is the moment in the beam as a function of *x*, *I* is the effective moment of inertia, and *h* is the thickness of silicon membrane.

The electrical displacement and internal stress of piezoelectric material is described as

$$\begin{bmatrix} D \\ \delta \end{bmatrix} = \begin{bmatrix} d & \varepsilon \\ 1/Y_c & -d \end{bmatrix} \begin{bmatrix} \sigma \\ E \end{bmatrix}$$

where, *D* is the electrical displacement, δ is the strain, *d* is the piezoelectric constant, ε is the dielectric constant, σ is the stress, and *Yc* is the Young's modulus. The open circuit voltage can be derived from the electric displacement tem in (5) as following.

$$v_{oc} = \frac{d\sigma g}{\varepsilon}$$

where, σxx is stress in x direction. Therefore, this configuration also has an advance in forward bias of rectifying diodes circuit because the generated open circuit voltage (*VOC*) is strongly affected by gap of electrodes (*g*) and piezoelectric coefficient (*d*). Furthermore, the piezoelectric constant in d33 mode is two or three times larger than d31 mode and electrode gap can be easily defined while the increasing of thickness of PZT thin film has limitations due to fabrication process.

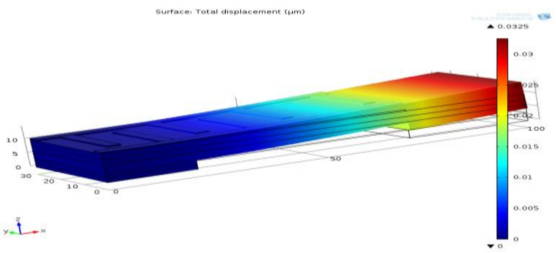

Fig. 4 Simulation of Displacement in Comsol Software

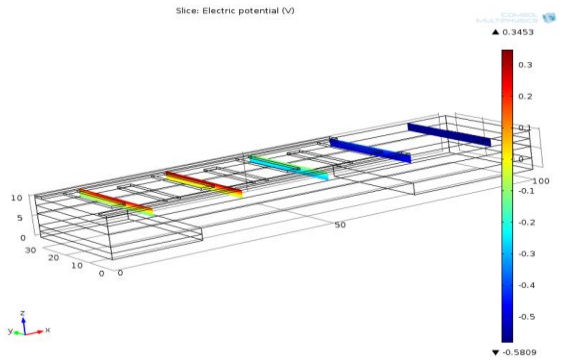

Fig. 5 Simulation of Voltage in Comsol Software

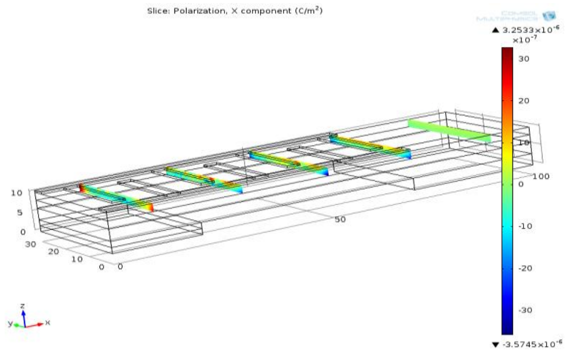

Fig. 6 Simulation of Polarization in Comsol Software

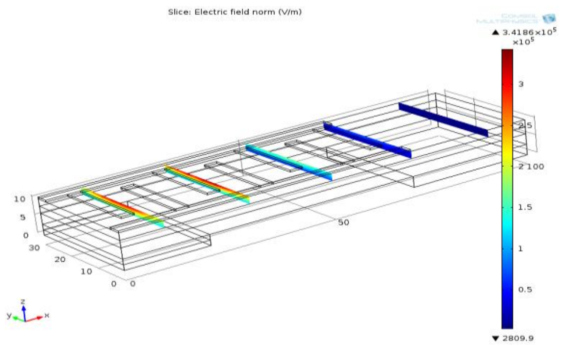

Fig. 7 Simulation of Electric Fieldin Comsol Software

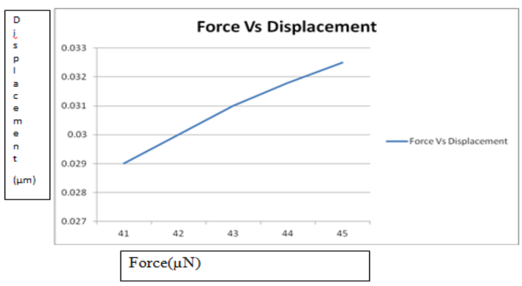

Fig. 8 Graph between force and displacement

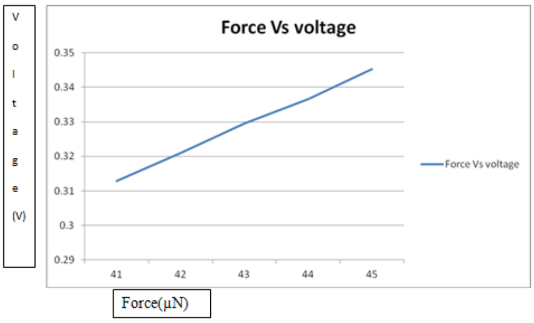

Fig. 9 Graph between force and voltage

III. CONCLUSION

This paper presented a piezoelectric MEMS energy harvester which was targeted to scavenge low-level ambient vibration energy. It was optimally designed with multi-layered cantilever structure with Si proof mass for adjusting resonant frequency and reducing spring constant. In order to achieve large output voltage, the inter-digital shaped electrodes were applied for d33 mode operation. The d33 piezoelectric mode has several advantages such as constant stress-strain distribution between electrodes and larger piezoelectric constant than conventional d31 mode.

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