A NEW POLING METHOD FOR HIGH POWER GENERTOR USING PZT CERAMIC

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Abstract: In this paper, the feasibility of a way to improve the output power from the PZT based energy harvester is demonstrated with introducing a new poling method in order to enhance the piezoelectric performance of the PZT material. A PZT (lead zirconate titanate Pb(Zr,Ti)O$_3$) based energy harvester is designed, fabricated, and characterized with applying a new poling method. This PZT cantilever is used d$_{31}$ mode to generate the electrical power. As a result, the PZT based power generator with the dimension of 7mm×3mm×0.03mm generates 40µW with the application of 1 MV/m pulse mode voltage from 1g acceleration at its resonant frequency of 942 Hz. Under the same conditions, this device shows the result of 33µW power with application of 1 MV/m DC voltage.

INTRODUCTION

Nowadays, the increasing demands upon mobile devices such as wireless sensor networks and the recent advent of low power electrical devices such as MEMS make such renewable power sources attractive [1]. However, traditional power sources such as batteries have limitations in the applications of these fields due to the large size, limited lifetime, and environmental pollution. Therefore, a large effort is ongoing to compensate for these disadvantages of batteries for the applications of those fields and to replace the batteries with more efficient and longer lasting power solutions [2]. One of the clues to alleviating these issues is to utilize the energy harvesting devices. The goal of the energy harvesting device is to capture the normally wasted energy or environmental energy surrounding a system and convert it into usable energy for the electrical device to consume.

One of the wasted sources utilized in the energy harvesting devices is the ambient vibrations present around most machines and biological systems. This vibrational source of energy can be converted into the electrical energy by using of the characteristic of piezoelectric materials, which have the ability to convert mechanical strain energy into electrical energy and vice versa [1, 2].

Much works have been done in order to harvest the energy utilizing piezoelectric material over the past few decades [3]. However, the energy produced by these materials is in many cases far too small to directly power an electrical device. Therefore, much of the research into power harvesting has focused on methods of accumulating the energy until a sufficient amount is present, allowing the intended electronics to be powered.

Therefore, in this study, a new poling method is proposed to improve the performance of the energy harvesting device.

DESIGN AND SIMULATION

The magnitude of power from vibration based energy harvester is closely related to the many parameters as follows: mass, material properties, vibration amplitude, vibration frequency, etc.

Note that the power output at the d$_{31}$ mode is generally expressed as follows:

$$V_{31} = \frac{Fg_{31}T}{LW}$$
$$Q_{31} = Fd_{31}$$
$$P_{31} = V_{31}Q_{31}f = \sigma^2{}_{31}d_{31}g_{31}TWLf \qquad (1)$$

Where P_{31} is the generated power, Q_{31} is the quantity of electric charge, f is the natural frequency of energy harvester, d_{31} is the piezoelectric strain constant and g_{31} is the piezoelectric stress constant at the d_{31} mode, respectively

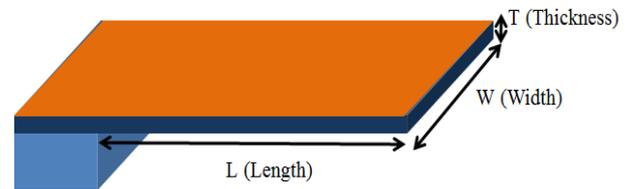Figure 1 shows the Schematic of a d$_{31}$ mode based PZT cantilever,

Fig. 1: A schematic diagram of a d$_{31}$ mode based PZT cantilever

If the dimension and the vibration type of the cantilever in Figure 1 are fixed and the values of d_{31} and g_{31} are increased, we can get higher power from the vibration based energy harvester. Therefore, we studied ways to increase the value of d_{31} and g_{31} for realizing the improved energy harvester.

In this paper, we can realize the goal with introducing a new poling method based on the appliance of pulse mode voltage and making the resonance frequency of the cantilever lower.

Figure 2 and 3 show the simulated results of the deflection and the resonance frequency of the PZT based cantilever by using ANSYS. The dimension of the designed cantilever is 7mm×7mm×0.03mm and the simulated resonance frequency of this cantilever is about 915 Hz. To reduce the analysis time and error, the mesh density at the fixed part is designed very densely.
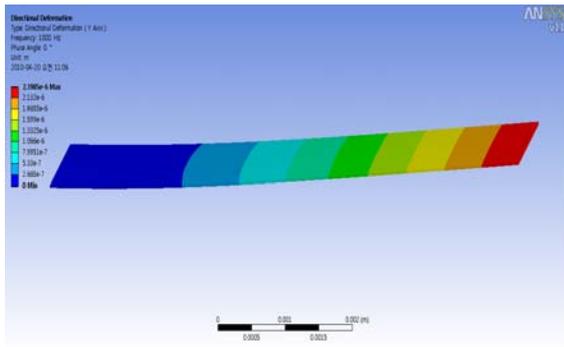

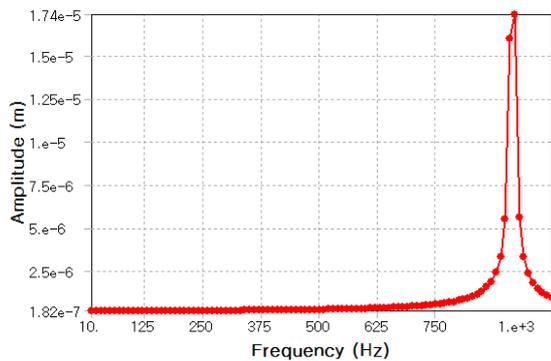*Fig. 2:   The simulated deformation analysis of the cantilever*

Fig. 3:   The simulated frequency analysis of the cantilever

FABRICATION

For the test of the feasibility of the proposed method, PZT based cantilever for realizing an energy harvester is fabricated by the micromachining process.

The basic structure of designed cantilever is consisted of four layers as follows: a silicon dioxide layer (SiO$_2$) for controlling the deflection of the cantilever structure, a bottom electrode, a piezoelectric layer (PZT) and a top electrode.

The fabrication sequence of the PZT based cantilever is shown in Figure 4.

The process starts on deposition of silicon dioxide insulation layer on silicon wafer using LPCVD (Figure 4-1). The 2μm thick SiO$_2$ layer with low residual stress

and high purity also plays a role as a mechanical supporting layer for piezoelectric ceramic layer. And then 200Å thick titanium layer and 2000Å thick platinum layer are deposited for the adhesion layer and the bottom electrode by RF sputter (Figure 4-2).

A PZT solution (Inostek co.) is spun onto the deposited layer with a spin speed of 300 rpm for 5 sec and a spin speed of 1000 rpm for 30 sec.
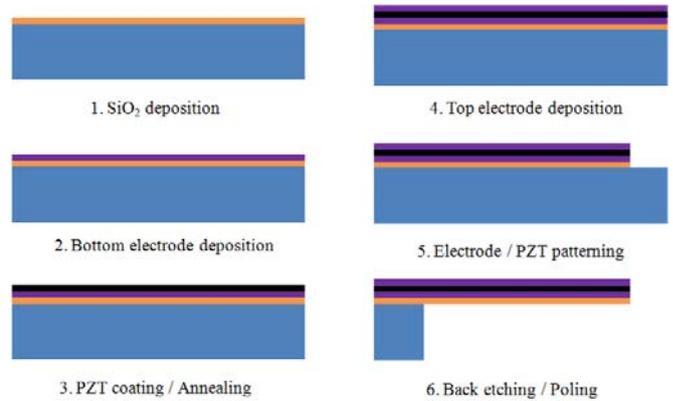

Fig. 4: The fabrication sequence of the PZT based cantilever.

And this PZT gel layer is pyrolyzed at 300℃ for 3 min on a hot plate seven times repeatedly with same conditions yielding a final thickness of PZT of approximately 30μm. The PZT layer is then annealed at 850℃ for 10min in the furnace (Figure 4-3). And 200Å thick titanium layer and 2000Å thick platinum layer are deposited for the adhesion layer and the top electrode by RF sputter (Figure 4-4). And to define the length of PZT based cantilever, photoresist (MicroChem AZ4620) is spun onto the top electrode layer and patterned. And the top electrode layer is etched using wet etching process. Then the PZT layer is anisotropically patterned using deep reactive ion etching (DRIE) process and the bottom electrode is patterned using wet etching process (Figure 4-5).

Finally, the back side of silicon wafer is etched using DRIE process to form the cantilever structure of the energy harvesting device (Figure 4-6).

To improve the characteristics of the PZT film, a poling process is introduced to the deposited PZT film.

Usually a poling process is done with very high electric field environment and also at very high temperature environment above Curie temperature.

The dipoles in the PZT material tend to move freely above the Curie temperature. The curie temperature of the PZT material in this work is approximately 220℃.

To form the pole in the PZT material in this experiment, two types of electric field are applied to the PZT layer as follows : an intensity of 1 MV/m DC electric field and an intensity of 1 MV/m pulse mode based electric field.

Figure 5 shows the finally fabricated PZT cantilever after the poling process.

Fig. 5: the photograph of the fabricated PZT cantilever

EXPERIMENTAL RESULTS

The resonance frequency of the fabricated cantilever with the dimension of 7mm×7mm×0.03mm has been measured using vibration shaker. Measured resonance frequency is approximately 942 Hz. And the simulated resonance frequency of PZT based cantilever is 915 Hz.

This difference could be explained by the non-homogeneous characteristic of the deposited PZT material.

In order to make an alignment of the dipoles in the PZT layer, an intensity of 1 MV/m electric field with pulsed mode type is applied to the PZT layer. And the pulse duration time and off-time of this electric field are 40msec and 10msec respectively

Table 1 shows the applied conditions for poling the PZT based cantilever beams.

Table 1: Experimental conditions

	Condition 1	Condition 2
Voltage mode	DC voltage	Pulse voltage (On : 40msec, Off : 10msec)
Poling temperature	120℃	120℃
Distance between electrodes	30μm	30μm
Poling electric field strength	1 MV/m	1 MV/m
Poling time	30 min	30 min

Figure 6 and 7 show the output voltage and the output power according to the variance of the load impedance. As shown in these results, the PZT based power generator generates the maximum power value of 40μW with pulse mode voltage from the conditions of 1g acceleration at its resonant frequency of 942 Hz. However, the maximum power is obtained the value of 33μW from the application of DC voltage with the same conditions. This difference could be explained by the difference of the poling mechanism between the applications of pulse mode voltage and DC mode voltage.

Usually, when an electric field is applied to the PZT material, the dipole in the PZT material tries to make an alignment with remaining fine cracks. However, these fine cracks make the piezoelectric performance of the PZT material deteriorate.

The Dipoles in PZT material remain more fine cracks with the DC mode voltage than pulse mode voltage [7].
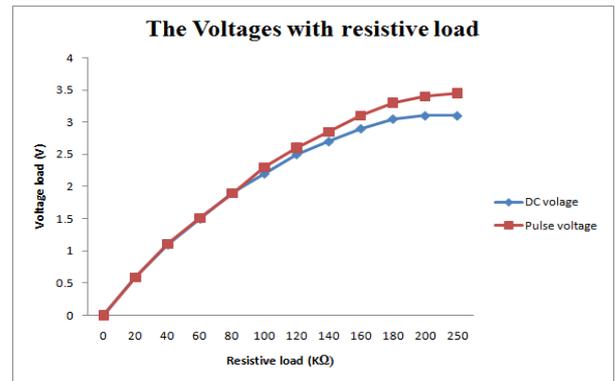

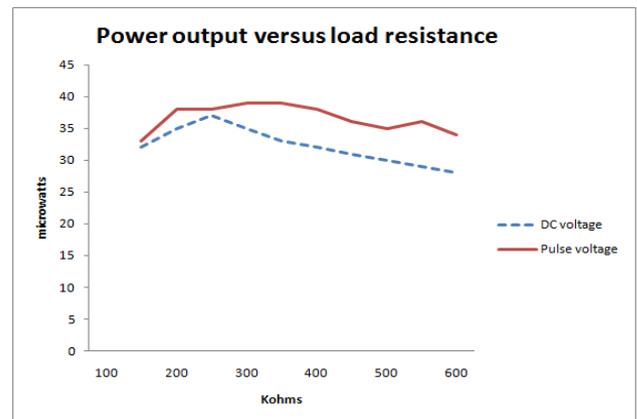*Fig. 6: The output voltage with the variance of the load impedance.*

Fig. 7: The output power with the variance of the load impedance.

CONCLUSIONS

The PZT cantilever based energy harvester with the dimension of 7mm×3mm×0.03mm is fabricated using silicon-based micromachining technologies. The PZT based cantilever is polarized by poling process with pulse mode voltage to improve the piezoelectric performance of the energy harvesting device. The applied pulse electric field is 1 MV/m (Pulse duration time is 40msec and Off-time is 10msec). This PZT cantilever has the mechanical resonance frequency with 942 Hz. For the electrode it is used the d_{31} mode to generate the electrical power (See Fig. 1 and Fig. 5). As a result, the PZT based power generator generates 40μW with pulse mode voltage from 1g acceleration at

its resonant frequency of 942 Hz. Under the same conditions, this device shows the result of 33µW power with application of 1 MV/m DC voltage (See Fig. 6 and Fig. 7). The Dipoles in PZT material remain more fine cracks with the DC mode voltage than pulse mode voltage.

From this study, we demonstrate the feasibility of a way to improve the output power from the PZT based energy harvester. This PZT based energy harvester with the application of pulse mode voltage could be used for various applications such as batteryless micro sensors and micro power generators, etc.

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