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전극 구조에 따른 압전 진동 에너지 하베스팅의 성능연구
Effects of the Electrode Configurations on Piezoelectric Vibration Energy Harvesting

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1. Introduction

Energy harvesting is the process of acquiring the energy surrounding a system and converting it into usable electrical energy. One driving force behind the search for new energy harvesting devices is the desire to power sensor networks and mobile devices without batteries. Vibrations are the most pervasive source in the environment and enable many applications such as sensors embedded in advanced structures where solar or other ambient energy does not exist. Suitable vibrations can be found in numerous applications including common household goods (refrigerators, washing machines, microwave ovens etc.), industrial plant equipment, moving structures such as automobiles and aircraft and infrastructure such as buildings and bridges. Piezoelectric materials produce electrical charge or voltage across them when a mechanical stress or strain is applied, or vice versa. This functionality enables the use of piezoelectric materials to convert mechanical energy into electrical energy. Piezoelectric vibration energy harvesters (PVEHs) have received considerable attention because of their direct conversion, high conversion efficiency, and wide availability of piezoelectric materials.(1)

2. Electrode Configurations for PVEHs

Use of two different modes is common to operate PVEH devices: {3-1} mode of operation and {3-3} mode of operation. In {3-1} mode, the voltage (and therefore, electric field) acts in the “3” direction while the mechanical strain is applied in the “1” direction. In {3-3} mode, both strain and voltage occur in the same direction, “3”. Index “1” and “3” come from Cartesian coordinate directions. For simplicity of analysis in the {3-3} mode of operation, x_1 coincides with the beam thickness coordinate (x_t) while x_3 corresponds to general beam structure axial coordinate (x_a). Choice of electrode configuration is dependent upon the modes of operations. Standard capacitor type electrodes are employed for {3-1} modes of operation while interdigitated electrodes (IDTEs) are commonly used to implement {3-3} modes of operation (see Figures 1 and 2). {3-3} mode of operation is advantageous in that the voltage developed can be controlled. While the electrode spacing is determined by the thickness of the piezoelectric layer in {3-1} mode, the electrode spacing determines the voltage produced in {3-3} mode configuration and can therefore be varied in design. In microsystems, there is a limitation in the thickness of piezoelectric layer that can be deposited due to the microfabrication processing, and thus, the voltage that can be obtained from {3-1} mode will be limited as well.

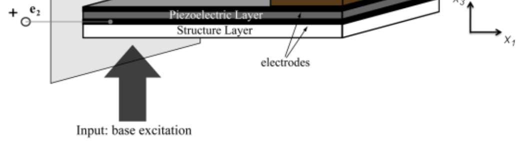

Figure 1 Unimorph cantilevered piezoelectric energy harvester device in {3-1} mode of operation with standard electrode configuration.

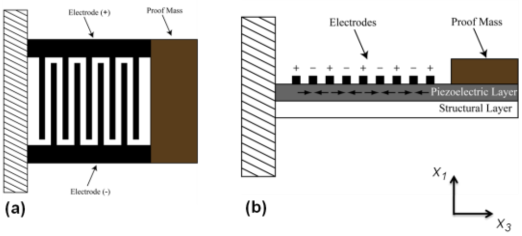

Figure 2 Interdigitated electrode (IDTE) configuration in cantilevered piezoelectric energy harvesting {3-3} mode devices: (a) top-view and (b) side-view.

However, once we have a series of PVEHs on a single die as a final system, it is possible to control the electrical output of the entire system by controlling the interconnections of individual devices(2). Therefore, it implies that both modes of operations are potentially attractive for practical applications.

3. Analytical Modeling and Experimental Evaluation for Different Electrode Configurations

In this work, detailed analytical models for different electrode configurations in PVEHs were developed. The model was then implemented and compared with the experimental test results of fabricated MEMS-PVEH devices both in {3-1} and {3-3} modes of operation (Figure 3). Electrical device responses, voltage and power, of the fabricated MEMS-scale device in {3-1} mode of operation were measured at the experimental "resonance" condition while keeping the base acceleration constant at 0.25 g (g =9.8 m/s^2). In Figure 4, measured electrical performance is plotted against electrical resistances ranging from 0 kΩ to 100 kΩ (dots) along with the simulated results (lines) for voltage and power at various damping conditions.

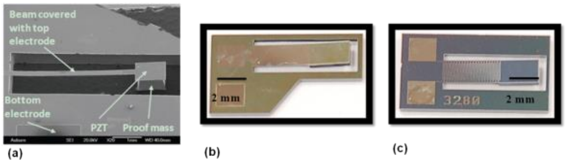

Figure 3 Fabricated, unimorph, MEMS-scale PVEH: (a) SEM image(3) and (b) optical image of a MEMS-scale PZT cantilever in {3-1} mode with a proof mass, (c) optical image of a MEMS-scale PZT cantilever with a proof mass in {3-3} mode with IDTEs. (b), (c) courtesy of Dr. Jung-Hyun Park.

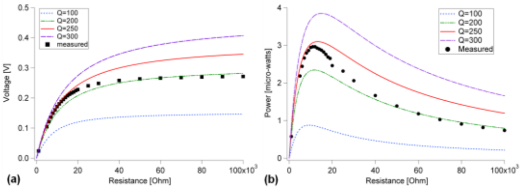

Figure 4 Model-experiment comparisons for a MEMS unimorph energy harvesting PZT cantilever in {3-1} mode.

Model-experiment comparison shows that trends of electrical behavior are well predicted regardless of quality factors. In terms of magnitudes, simulated voltage and power match well with the experimental results when the quality factor, Q, is close to 250 for the MEMS-PVEH in {3-1} mode. Predicted results of power at various damping conditions reveal that the values of maximum power and corresponding electrical resistances vary depending on the magnitudes of quality factor, implying the significance of quantifying the operating environment, especially, damping conditions of the MEMS-scale system.

4. Conclusions

In summary, the developed model for PVEH devices exhibits conservative predictive capability not only on macroscopic devices but also on MEMS-scale PVEHs.

References

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